National Water-Quality Assessment Program

Effects of Urbanization on Stream Ecosystems Along an Agriculture-to-Urban Land-Use Gradient, Milwaukee to Green Bay, Wisconsin, 2003–2004

Chapter E of
Effects of Urbanization on Stream Ecosystems in
Six Metropolitan Areas of the United States

Scientific Investigations Report 2006–5101–E

U.S. Department of the Interior
U.S. Geological Survey

Cover: Milwaukee River at Milwaukee, Wis., near downtown riverwalk
Barbara C. Scudder, April 12, 2009.

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By Kevin D. Richards, Barbara C. Scudder, Faith A. Fitzpatrick, Jeffery J. Steuer, Amanda H. Bell, Marie C. Peppler, Jana S. Stewart, and Mitchell A. Harris

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KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director, Director

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Foreword

The U.S. Geological Survey (USGS) is committed to providing the Nation with credible scientific information that helps to enhance and protect the overall quality of life and that facilitates effective management of water, biological, energy, and mineral resources (http://www.usgs.gov/). Information on the Nation's water resources is critical to ensuring long-term availability of water that is safe for drinking and recreation and is suitable for industry, irrigation, and fish and wildlife. Population growth and increasing demands for water make the availability of that water, now measured in terms of quantity and quality, even more essential to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program in 1991 to support national, regional, State, and local information needs and decisions related to water-quality management and policy (http://water.usgs.gov/nawqa). The NAWQA Program is designed to answer: What is the condition of our Nation's streams and groundwater? How are conditions changing over time? How do natural features and human activities affect the quality of streams and groundwater, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues and priorities. From 1991–2001, the NAWQA Program completed interdisciplinary assessments and established a baseline understanding of water-quality conditions in 51 of the Nation's river basins and aquifers, referred to as Study Units (http://water.usgs.gov/nawqa/studyu.html).

In the second decade of the Program (2001–2012), a major focus is on regional assessments of water-quality conditions and trends. These regional assessments are based on major river basins and principal aquifers, which encompass larger regions of the country than the Study Units. Regional assessments extend the findings in the Study Units by filling critical gaps in characterizing the quality of surface water and groundwater, and by determining status and trends at sites that have been consistently monitored for more than a decade. In addition, the regional assessments continue to build an understanding of how natural features and human activities affect water quality. Many of the regional assessments employ modeling and other scientific tools, developed on the basis of data collected at individual sites, to help extend knowledge of water quality to unmonitored, yet comparable areas within the regions. The models thereby enhance the value of our existing data and our understanding of the hydrologic system. In addition, the models are useful in evaluating various resource-management scenarios and in predicting how our actions, such as reducing or managing nonpoint and point sources of contamination, land conversion, and altering flow and (or) pumping regimes, are likely to affect water conditions within a region.

Other activities planned during the second decade include continuing national syntheses of information on pesticides, volatile organic compounds (VOCs), nutrients, selected trace elements, and aquatic ecology; and continuing national topical studies on the fate of agricultural chemicals, effects of urbanization on stream ecosystems, bioaccumulation of mercury in stream ecosystems, effects of nutrient enrichment on stream ecosystems, and transport of contaminants to public-supply wells.

The USGS aims to disseminate credible, timely, and relevant science information to address practical and effective water-resource management and strategies that protect and restore water quality. We hope this NAWQA publication will provide you with insights and information to meet your needs, and will foster increased citizen awareness and involvement in the protection and restoration of our Nation's waters.

The USGS recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for cost-effective management, regulation, and conservation of our Nation's water resources. The NAWQA Program, therefore, depends on advice and information from other agencies—Federal, State, regional, interstate, Tribal, and local—as well as nongovernmental organizations, industry, academia, and other stakeholder groups. Your assistance and suggestions are greatly appreciated.

Matthew C. Larsen
Associate Director for Water

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Conversion Factors, Datums, and Miscellaneous Abbreviations

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
angstrom (A)	1.00 × 10-08	centimeter (cm)
kilometer (km)	0.6214	mile (mi)
	Area	
square meter (m^2)	0.0002471	acre
square meter (m^2)	10.76	square foot (ft^2)
square kilometers (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	0.2642	gallon (gal)
milliliter (mL)	0.0002642	gallon
milliliter (mL)	1000	microliter (µL)
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	1.308	cubic yard (yd^3)
	Flow rate	
cubic meter per second (m^3/s)	70.07	acre-foot per day (acre-ft/d)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
meter per second (m/s)	3.281	foot per sec (ft/s)
	Mass	
milligram (mg)	0.00000003527	ounce, avoirdupois (oz)
microgram (µg)	0.00003527	ounce, avoirdupois (oz)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8×°C)+32$$

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Miscellanoues Abbreviations

AhR	aryl hydrocarbon receptor
CERC	Columbia Environmental Research Center
CSS	combined-sewer system
CCA	Canonical Correspondence Analysis
DTH	depositional-targeted habitat
DCA	Detrended Correspondence Analysis
EUSE	Effects of Urbanization on Stream Ecosystems
EPT	Ephemeroptera, Plecoptera, Trichoptera
GIS	geographic information system
HCM	hydrologic condition metrics
HEC-RAS	Hydrologic Engineering Centers-River Analysis System
IBI	Index of Biotic Integrity
MISTE	missing streamflow estimation
NED	National Elevation Dataset
NLCD	National Land Cover Dataset
NWIS	National Water Information System
NAWQA	National Water-Quality Assessment
NWQL	National Water-Quality Laboratory
PCA	pentachloroanisole
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PTI	pesticide toxicity index
QMH	qualitative multi-habitat
RBP	Rapid Bioassessment Protocol
RTH	richest-targeted habitat
SPMD	semipermeable membrane device
SWTP	Southeastern Wisconsin Till Plains
SC	specific conductance
TEQ	SPMD toxicity, CYP1A1 production (toxic equivalents)
UII	urban intensity index
UPAH	SPMD toxicity, ultraviolet fluorescence (micrograms pyrene)
USEPA	U.S. Environmental Protection Agency
USACE	U.S. Army Corp of Engineers
USGS	U.S. Geological Survey
WDNR	Wisconsin Department of Natural Resources
WMIC	Western Lake Michigan Drainages

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Abstract

In 2003 and 2004, 30 streams near Milwaukee and Green Bay, Wisconsin, were part of a national study by the U.S. Geological Survey to assess urbanization effects on physical, chemical, and biological characteristics along an agriculture-to-urban land-use gradient. A geographic information system was used to characterize natural landscape features that define the environmental setting and the degree of urbanization within each stream watershed. A combination of land cover, socioeconomic, and infrastructure variables were integrated into a multi-metric urban intensity index, scaled from 0 to 100, and assigned to each stream site to identify a gradient of urbanization within relatively homogeneous environmental settings. The 35 variables used to develop the final urban intensity index characterized the degree of urbanization and included road infrastructure (road area and road traffic index), 100-meter riparian land cover (percentage of impervious surface, shrubland, and agriculture), watershed land cover (percentage of impervious surface, developed/urban land, shrubland, and agriculture), and 26 socioeconomic variables (U.S. Census Bureau, 2001). Characteristics examined as part of this study included: habitat, hydrology, stream temperature, water chemistry (chloride, sulfate, nutrients, dissolved and particulate organic and inorganic carbon, pesticides, and suspended sediment), benthic algae, benthic invertebrates, and fish. Semipermeable membrane devices (SPMDs) were used to assess the potential for bioconcentration of hydrophobic organic contaminants (specifically polycyclic aromatic hydrocarbons, polychlorinated biphenyls, and organochlorine and pyrethroid insecticides) in biological membranes, such as the gills of fish.

Physical habitat measurements reflective of channel enlargement, including bankfull channel size and bank erosion, increased with increasing urbanization within the watershed. In this study, percentage of riffles and streambed substrate size were more strongly related to local geologic setting, slope, watershed topography, and river-engineering practices than to urbanization. Historical local river-engineering features such as channelization, bank stabilization, and grade controls may have confounded relations among habitat characteristics and urbanization.

A number of hydrologic-condition metrics (including flashiness and duration of high flow during pre- or post-ice periods) showed strong relations to the urban intensity index. Hydrologic-condition metrics cannot be used alone to predict habitat or geomorphic change.

Chloride and SPMD measures of potential toxicity and polycyclic aromatic hydrocarbon concentrations showed the strongest positive correlations to urbanization including increases in road infrastructure, percentage of impervious surface in the watershed, urban land cover, and land-distribution related to urban land cover. This suggests that automobiles and the infrastructure required to support automobiles are a significant source of these compounds in this study area. Chloride in spring and summer showed a significant positive correlation with the urban intensity index; concentrations increased with increasing road infrastructure, urban land cover, and a number of landscape variables related to urbanization. Spring concentrations of sulfate, prometon, and diazinon correlated to fewer urban characteristics than chloride, including increases in road infrastructure, percentage of impervious surface, and urban land cover.

Changes in biological communities correlated to the urban intensity index or individual urban-associated variables. Decreased percentages of pollution-sensitive diatoms and diatoms requiring high dissolved-oxygen saturation correlated to increases in the percentage of developed urban land, total impervious surface, stream flashiness, population density, road-area density, and decreases in the percentage of wetland in the watershed. Invertebrate taxa richness and Coleoptera taxa richness decreased with increasing population density, developed urban land, impervious surface, and road length in the watershed, and invertebrate abundance decreased with increasing summer chloride concentrations. Decreases in fish IBI scores, total number of fish taxa, and number of native fish taxa correlated to increasing values of the urban intensity index, medium and high-intensity developed urban land in the watershed or 100-m riparian zone, total impervious surface, stream flashiness, and chloride.

In multivariate analyses with biological assemblages, total impervious surface in the watershed was used as a representative for urban landscape variables, chloride, and road-infrastructure variables because of the high degree of correlation among these characteristics. The most important environmental characteristics defining algal assemblages were primarily the percentage of woody wetlands in the watershed, spring nitrate and summer bicarbonate and total phosphorus concentrations, percentage of runs, and total impervious surface. The most important environmental characteristics for invertebrates were stream discharge in the spring and when the discharge exceeded 50 percent of the time as normalized by drainage area, total impervious surface, and the hydrologic-condition metric Richards-Baker flashiness index. Environmental characteristics defining fish assemblages were primarily total impervious surface and several environmental characteristics not necessarily related to urbanization: spring herbicide detections, percentage of pools, watershed slope, maximum instantaneous peak flow normalized by drainage area, summer dissolved oxygen, stream-bank vegetative cover, and summer pesticide toxicity-index values for cladocerans. The fish Index of Biotic Integrity was a reliable indicator of fish assemblage relations to urbanization when metric correlations and results of multivariate analyses were compared. Results from this study emphasize the importance of assessing multiple indicators of urbanization—geomorphology, land use/land cover, hydrology, and chemistry—to understand potential effects on aquatic biota in urbanizing streams.

Introduction

Urbanization is a major concern for water-resource managers, engineers, geomorphologists, and aquatic ecologists (Leopold, 1968; American Society of Civil Engineers, 1969; Spieker, 1970; The H. John Heinz III Center, 2002). The National Water-Quality Assessment program (NAWQA) of the U.S. Geological Survey (USGS) is investigating the effects of urbanization on stream ecosystems in selected metropolitan areas across the U.S. In all of these studies, urbanization is defined as the conversion of rural lands (agriculture or forest) to residential and commercial use (Couch and Hamilton, 2002). Urbanization has been linked to environmental problems related to degradation of water quality; loss of aquatic habitat; and changes in aquatic algal, invertebrate, and fish assemblages. Urban development affects stream hydraulics and sediment input, transport, and deposition, thereby altering aquatic habitat and aquatic biological communities (Garie and McIntosh, 1986; Yoder and Rankin, 1996; Kennen, 1999; Paul and Meyer, 2001). Previous studies of streams have shown that biotic integrity degrades at low levels of urbanization (Booth and Reinelt, 1993; Booth and Jackson, 1997; Maxted and Shaver, 1997; Wang and others, 2000; 2001). Results from urban studies in Wisconsin and Illinois indicate that fish Index of Biotic Integrity (IBI) scores tend to be low in watersheds with greater than 10 to 25 percent urban land and about 100 to 200 people per square kilometer (Wang and others, 1997; Dreher, 1997; Fitzpatrick and others, 2004). In general, abundance and diversity of aquatic biota decrease with increased urbanization of stream basins (Paul and Meyer, 2001); however, species richness may increase with low to moderate urbanization because of non-native species introduction and increases in adaptable native species (McKinley, 2006). Altered flow regimes can result in algal blooms and dying aquatic biota associated with lower oxygen levels; burying biota under fine sediment; flushing biota downstream; and disrupting normal feeding, resting, and swimming patterns (Finkenbine and others, 2000). In addition, increasing chemical concentrations cause shifts in aquatic biological communities to more pollution-tolerant species. Ultimately, urban impacts on native biota can lead to increased vulnerability of aquatic biological communities to non-native/exotic species.

Land cover is one of the most important watershed characteristics that may influence stream water quality (Chang, 1988). In urban and suburban areas, much of the land surface is covered by impervious surfaces, including buildings and pavement. When land is converted from rural to urban, impervious surface area (roads, sidewalks, driveways, parking areas, rooftops) increases, resulting in decreased infiltration and increased rate and volume of surface runoff. Pervious surfaces are compacted by construction equipment and removal of topsoil. Drainage networks are extended through ditching and construction of storm sewers. These factors result in changes in the frequency, duration, and size of floods (Hollis, 1975; Booth, 1990; Booth and Jackson, 1997; Konrad, 2003). Relative increases may be greater for small, frequent floods than for large, infrequent floods (Krug and Goddard, 1986; Konrad, 2003). Decreases in infiltration may result in decreases in the water table and ultimately decreases in base flow (Finkenbine and others, 2000). These offsets, however, may be compensated for by contributions from point sources (LaTour, 1993). Although stormwater-detention ponds and other control measures designed to slow runoff to streams are becoming common in urban areas, they may not meet design goals of controlling surface runoff (Booth and Jackson, 1997; Finkenbine and others, 2000).

The relation between urbanization and stream-habitat degradation is complex; and direct cause-and-effect relations can be difficult to discern because increases in runoff can cause multiple geomorphic responses that are variable in space and time (Schumm, 1960; Gregory and Madew, 1982). In addition to changes in the amount and timing of runoff, geomorphic responses are affected by other boundary conditions such as geologic setting, slope, stream-network position, base level (elevation), and history (Fitzpatrick and others, 2006). Channel erosion (through incision or widening) or sedimentation may result from urban development (Wolman, 1967; Wolman and Schick, 1967; Guy, 1970;

Graf, 1975; Roberts, 1989; Booth, 1990; Gregory and others, 1992; Booth and Jackson, 1997; Trimble, 1997; Colosimo, 2002). Channel enlargement (increase in channel size through incision or widening) commonly occurs in urbanizing streams (Hammer, 1972; Doll and others, 2002; Center for Watershed Protection, 2003) but is dependent on erodibility potential of the channel bed and banks and local sediment transport characteristics. The amount of fine substrate may decrease from altered hydrology (Finkenbine and others, 2000). Sediment loads may increase during initial urban construction and decrease to pre-development loads after construction (Wolman, 1967; Wolman and Schick, 1967; Colosimo, 2002).

Some studies show relations among stream habitat characteristics and urban development, whereas other studies do not (Booth and Jackson, 1997; Paul and Meyer, 2001; Wang and others, 2001; Rogers and others, 2002; Fitzpatrick and others, 2004; Fitzpatrick and others, 2005). Habitat indices are not always a reliable indicator of geomorphic responses to urbanization; either because the component metrics are not unique in describing geomorphic processes or metrics are not sensitive enough to quantify urban-related geomorphic change (Fitzpatrick and others, 2004). Some studies looked at individual metrics (forming a habitat index), including measures of riffle/pool quality; bank stability; embeddedness; amount of fine substrate; and amount of large, woody debris (Finkenbine and others, 2000; Paul and Meyer, 2001; Center for Watershed Protection, 2003). In the Pacific Northwest, increased bank erosion and lack of large woody debris was associated with increases in urbanization (Booth, 1991; Finkenbine and others, 2000). Few data are available, however, for urbanization effects on riparian canopy, wetted perimeter, velocity/depth regimes, riffle frequency, and sediment deposition in pools (Center for Watershed Protection, 2003). Slope and substrate may have a large influence on how stream habitat responds to urbanization: streams with steep slopes and rocky substrates are more likely to have good habitat quality and biotic integrity than streams with flat slopes and fine-grained substrates (Wang and others, 1997).

Streamwater chemistry is another contributor to the health of urban-stream ecosystems. The National Water Quality Inventory 2000 Report to Congress identified pollutants associated with urban runoff as one of the leading sources of water-quality impairment in surface waters (U.S. Environmental Protection Agency, 2002a). The variety and amount of pollutants reaching streams and lakes often increases with increased urbanization. These pollutants can include nutrients and pesticides (from lawns, gardens, golf courses, and parks), road salts, metals, and hydrocarbons (from transportation corridors), sediment (from construction areas), viruses and bacteria (from leaking sanitary-sewer and septic systems and pet waste), and thermal pollution (increased temperature of runoff resulting from dark, impervious surfaces). Contaminants can also enter streams from wastewater-treatment plants and industrial sources. Nationwide, it is estimated that urban runoff accounts for 43 percent of impaired estuary acres, 24 percent of impaired lake acres, and 11 percent of impaired river miles (U.S. Environmental Protection Agency, 1992). Updated estimates implicate urban runoff in the impairment of 34,781 river miles or 13 percent of assessed stream miles in the United States (U.S. Environmental Protection Agency, 2002a).

Land-cover gradient and space-for-time approaches have been used to examine urbanization effects on aquatic biological communities, habitat, and geomorphic and hydrologic conditions (Booth and Reinelt, 1993; Dreher, 1997; Wang and others, 2001). Various measures have been used to represent urbanization, including impervious surface area (total and effective), amount of urban land, population density, and combinations of urban indicators (Schueler, 1994; Booth and Jackson, 1997; McMahon and Cuffney, 2000; Gergel and others, 2002). Urbanization in the Milwaukee-Green Bay area is replacing agricultural land that has been the dominant land use for many years; thus historical agricultural practices have affected the urbanizing streams. The percentage of watershed agricultural land is a major factor that negatively affects fish, macroinvertebrate, and habitat integrity in previously forested watersheds (Richards and others, 1996; Roth and others, 1996; Wang and others, 1997; Fitzpatrick and others, 2001; Stewart and others, 2001). Some agricultural streams near southeast Wisconsin, however, have high biotic integrity (Dreher, 1997; Wang and others, 1997; Fitzpatrick and others, 2004; Harris and others, 2005).

Previous studies have shown that the physical, chemical, and biological characteristics of streams are affected by urbanization. Few studies, however, have integrated multiple spatial scales of landscape and urban characteristics with reach-scale geomorphic, hydrologic, habitat, and aquatic biota characteristics (Roesner and Bledsoe, 2003). A goal of this study is to show how physical, chemical, and biological characteristics of streams may be affected by urbanization and how landscape characteristics or physiographic settings may moderate the extent of those effects.

Purpose and Scope

This report describes possible responses to urbanization in physical, chemical, and biological characteristics for 30 streams along an agriculture-to-urban land cover gradient in the Milwaukee to Green Bay, Wis., area (table 1). Data were collected during the 2004 water year (Oct. 1, 2003—Sept. 30, 2004). This study was part of a larger study of the Effects of Urbanization on Stream Ecosystems (EUSE) conducted by the USGS NAWQA program. The approach used a substitution of space for time, which assumes that temporal trends at a site (in this case, from increases in urban land and population) will be similar to spatial trends found among sites with varying amounts of urban land. The NAWQA Program also conducted similar studies in five other major urban areas of the U.S. during the same time period (Couch and Hamilton, 2002; Sprague and others, 2006; Falcone and others, 2007; Gregory and Calhoun, 2007; Waite and others, 2008) and pilot studies in other major urban areas prior to these studies.

Table 1. Location of study watersheds, watershed areas, and their urban intensity index values for 30 sites in the Milwaukee to Green Bay, Wis., study area.

(USGS, U.S. Geological Survey; km^2, square kilometer; dd°mm'ss", degrees, minutes, seconds; Cth, County Highway]

USGS streamflow-gaging station number	Site and watershed abbreviation	Site and watershed number	USGS site name	Latitude (dd°mm'ss")	Longitude (dd°mm'ss")	Drainage area (km^2)	Urban intensity index (UII)
04072233	LANC	1	Lancaster Brook at Shawano Avenue at Howard, Wis.	44°33'29"	88°06'10"	25.54	33.33
04078085	BLOT	2	Black Otter Creek near Hortonville, Wis.	44°20'09"	88°38'39"	41.04	26.49
04081897	SAWY	3	Sawyer Creek at Westhaven Road at Oshkosh, Wis.	44°00'55"	88°35'40"	30.60	32.60
04084429	MUDC	4	Mud Creek at Spencer Road at Appleton, Wis.	44°15'31"	88°27'42"	33.28	62.31
04084468	GARN	5	Garners Creek at Park Street at Kaukauna, Wis.	44°15'53"	88°18'19"	20.74	60.03
04085046	APPL	6	Apple Creek at Sniderville, Wis.	44°21'18"	88°11'28"	118.81	33.29
040850683	ASHW	7	Ashwaubenon Creek at South Bridge Rd near Depere, Wis.	44°24'51"	88°07'37"	51.82	21.51
040851235	BOWR	8	Bower Creek Trib at Lime Kiln Road near Bellevue, Wis.	44°27'09"	87°58'50"	34.39	37.97
040851325	BAIR	9	Baird Creek at Superior Road at Green Bay, Wis.	44°30'04"	87°56'10"	52.01	19.20
04085188	RIOC	10	Rio Creek at Pheasant Road near Rio Creek, Wis.	44°36'12"	87°31'37"	55.81	10.48
040851932	KEWA	11	Kewaunee River Trib at Lowell Road near Luxemburg, Wis.	44°35'33"	87°42'48"	36.72	13.78
04085270	JAMB	12	Jambo Creek at Jambo Creek Road near Mishicot, Wis.	44°15'43"	87°40'52"	48.83	.00
040853145	BLAK	13	Black Creek at Curran Road near Denmark, Wis.	44°20'14"	87°44'43"	56.13	4.18
04085322	DEVL	14	Devils River at Rosencrans Road near Maribel, Wis.	44°18'33"	87°49'36"	76.45	10.81
040854395	POIN	15	Point Creek at Ucker Point Road near Newton, Wis.	43°57'54"	87°43'34"	45.92	19.50
04085455	MEME	16	Meeme River at Washington Road near Cleveland, Wis.	43°54'49"	87°48'31"	50.41	6.96
04086699	PIGN	17	Pigeon Creek at Williamsburg Dr at Thiensville, Wis.	43°14'01"	87°59'08"	29.86	51.83
040869415	LINC	18	Lincoln Creek at 47th Street at Milwaukee, Wis.	43°05'49"	87°58'20"	25.96	100.00
04087030	MENO	19	Menomonee River at Menomonee Falls, Wis.	43°10'22"	88°06'14"	87.85	49.47
0408703164	LILY	20	Lily Creek at Good Hope Road near Menomonee Falls, Wis.	43°08'54"	88°04'53"	11.22	60.29
04087070	LTME	21	Little Menomonee River at Milwaukee, Wis.	43°07'25"	88°02'37"	51.70	71.54
040870856	UNDW	22	Underwood Creek at Watertown Plank Rd at Elm Grove, Wis.	43°02'34"	88°04'46"	24.56	74.82
04087118	HONY	23	Honey Creek near Portland Avenue at Wauwatosa, Wis.	43°02'32"	88°00'38"	27.74	85.24
04087204	OAKC	24	Oak Creek at South Milwaukee, Wis.	42°55'30"	87°52'12"	66.79	76.37
04087213	ROOT	25	Root River at Layton Avenue at Greenfield, Wis.	42°57'32"	88°02'24"	30.74	89.25
040872393	HOOD	26	Hoods Creek at Brook Road near Franksville, Wis.	42°46'22"	87°51'58"	38.93	31.26
04087258	PIKR	27	Pike River at Cth A near Kenosha, Wis.	42°39'13"	87°51'01"	100.29	53.05
04087270	PIKC	28	Pike Creek at 43rd Street at Kenosha, Wis.	42°35'49"	87°49'42"	16.30	83.23
05527729	KILB	29	Kilbourn Ditch at 60th Street near Kenosha, Wis.	42°34'56"	87°57'00"	53.71	27.36
055437901	FOXR	30	Fox River at River Road near Sussex, Wis.	43°06'27"	88°10'19"	60.79	39.99

By minimizing the natural variation across watersheds, the study could focus on the effects of urbanization on stream ecosystems across a low-to-high gradient of urbanization while the natural setting remained fairly constant. Thus, study watersheds were selected with relatively homogeneous environmental settings as characterized by geology, topography, climate, and drainage area. Physical, chemical, and biological data were collected at each site.

The objectives of the study were to (1) examine physical, chemical, and biological responses of streams along a gradient of urbanization; (2) determine the major physical, chemical, and landscape characteristics associated with aquatic biological communities; and (3) provide useful information to managers of water resources in the Milwaukee and Green Bay, Wis., study area. Descriptions of study design/site selection; field and analytical methods; and evaluation of the patterns of response of the physical, chemical, and biological characteristics to urbanization are summarized in this report.

Description of Study Area and Variability of Natural Landscape Characteristics

Sampled sites were within the southeastern part of the Western Lake Michigan Drainages (WMIC) Watershed near the Milwaukee and Green Bay metropolitan areas. The study area was primarily in the Southeastern Wisconsin Till Plains (SWTP) Level III ecoregion, although parts of the Central Corn Belt Plains and North Central Hardwood Forest ecoregion were included (fig. 1) (Omernik and others, 2000). Although Level III ecoregions provided a basic framework for defining a relatively homogeneous study area, it was necessary to further refine the study-area boundary, using the texture of Quaternary deposits. The texture of Quaternary deposits is variable in the SWTP and is known to influence the quality of stream reaches; these deposits affect overland and streambank-erosion rates, particle size of suspended and streambed sediment, vegetation, aquatic biota, and land-cover practices. The clayey surficial deposits of the southeastern part of the study area are glaciolacustrine in origin; the location of the clayey surficial deposits and 1:24,000-scale watershed boundaries were used to refine the study-area boundary (fig. 2) (Richmond and Fullerton, 1983, 1984; Peters, 1997; Wang and others, 1997; Fitzpatrick and others, 2005).

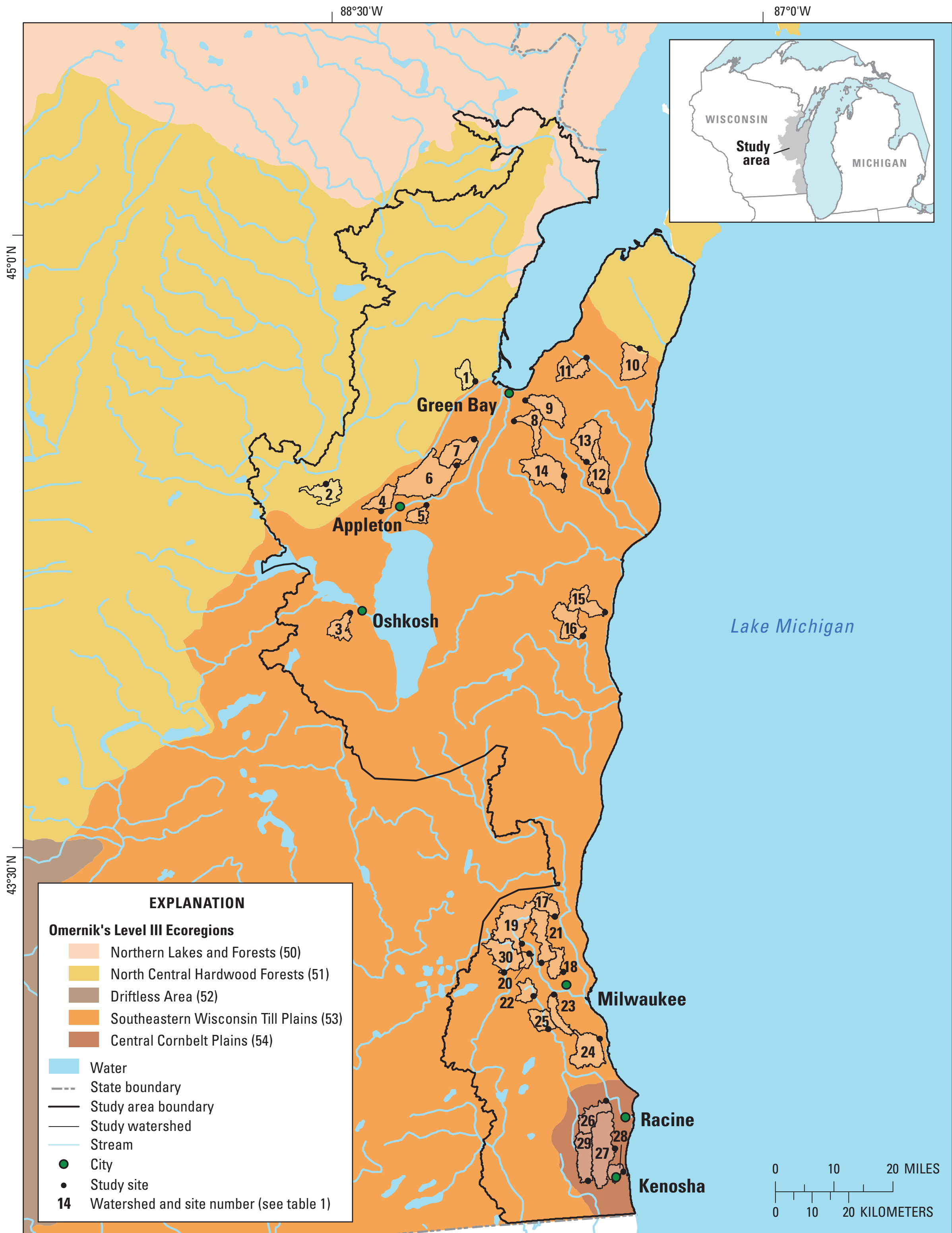
The physiographic setting of the study area includes the Interior Plains Division, Central Lowland Province, Eastern Lakes Section (Fenneman, 1938; Martin, 1965). Bedrock geology mainly consists of Silurian dolomite in the Milwaukee area and Ordovician dolomite and shale in the Green Bay area (Mudrey and others, 1982). The bedrock is buried by unconsolidated Quaternary deposits that vary in thickness from 0 to more than 120 m; shallower deposits are in the northern part of the study area (Soller and Packard, 1998). Sampled sites from both metropolitan areas have gentle watershed slopes (1.0–3.3 percent) (Falcone and others, 2007).

The climate of the study area is temperate continental with a mean annual air temperature of 6°C in the Green Bay area and 8°C in the Milwaukee area; mean annual precipitation ranged from 79 to 90 mm, 1980–1997 (Falcone and others, 2007; University of Montana Numerical Terradynamic Simulation Group, 2005). Precipitation normally falls in the five-month May through September period (Wendland and others, 1985). Climate in Milwaukee and Green Bay is modified by proximity to the Great Lakes, especially Lake Michigan, the Bay of Green Bay, and Lake Superior (Eichenlaub, 1979).

Land cover in the watersheds in this study consists of mainly agricultural and urban developed land; small amounts of forest and wetlands mainly are present in county forest preserves (fig. 3). Developed land ranged from 3 to 99 percent, and cultivated land ranged from 0 to 87 percent in the watersheds of the 30 sampled sites (fig. 4). Forests and wetlands within a 100-m riparian zone along the entire study stream network ranged from 0 to 34 percent (Falcone and others, 2007).

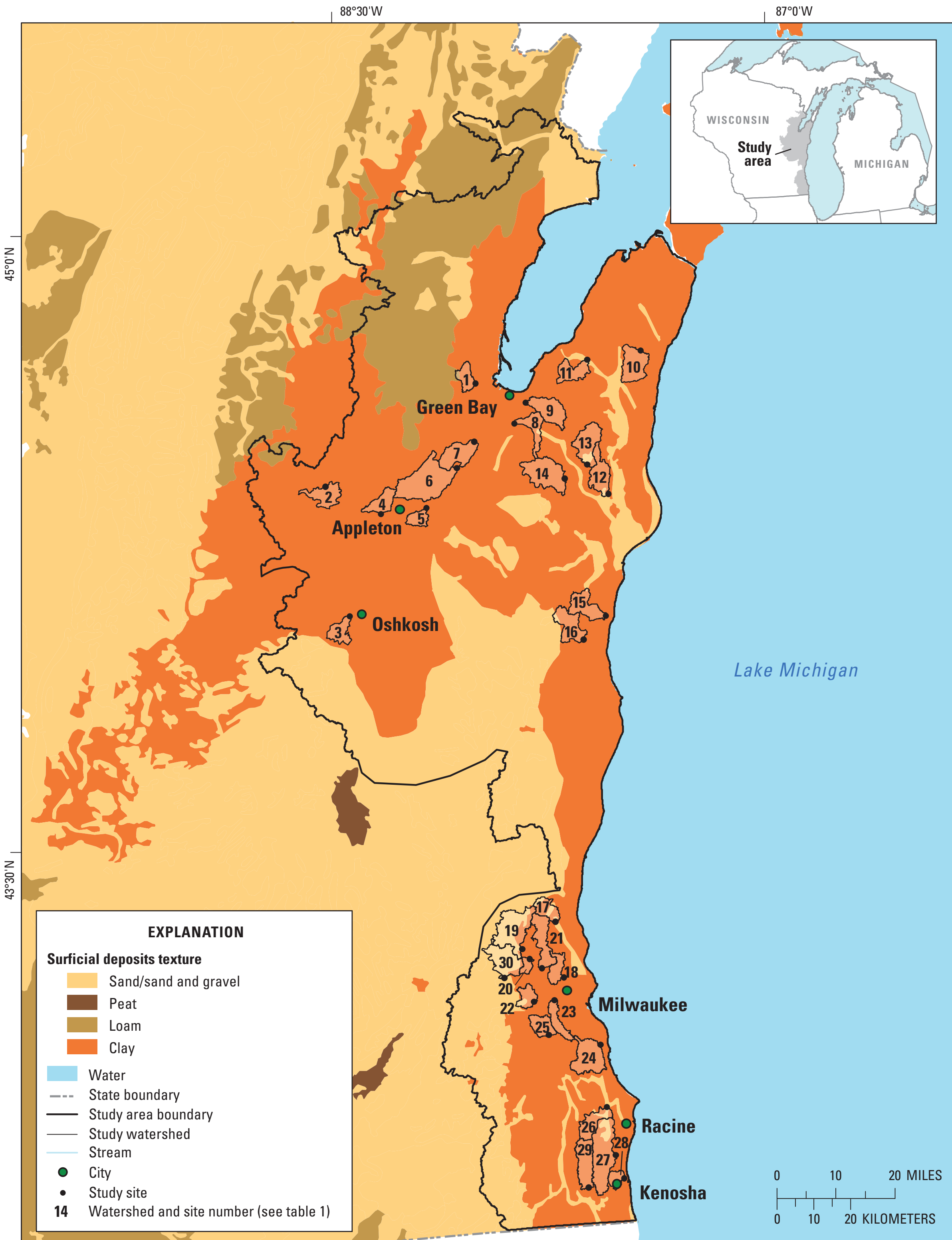
Urbanization patterns in the Milwaukee and Green Bay areas are similar to most metropolitan areas in the United States: urban land area is increasing but population density is decreasing (fig. 5). During 1982 to 1997, urban land in Green Bay increased by 33.8 percent; and population increased by 21.7 percent; population density decreased 9 percent (U.S. Census Bureau, 2001), fig. 6). Urban land in the Milwaukee area increased by almost 25 percent; population increased by 6.5 percent; population density decreased by almost 15 percent (fig. 7) (Fulton and others, 2001). Change in population density (1990–2000) for the 30 study watersheds ranged from a decrease of 16.2 percent for Jambo Creek, near Mishicot, to an increase of 138.3 percent for Sawyer Creek, near Oshkosh. Increases in urbanized (developed) land ranged from 1 percent for Baird Creek, near Green Bay to 45 percent for Garners Creek, near Kaukana.

Storm-water controls are used to protect homes and businesses from flooding and help keep runoff out of the sewer system, reducing the risk of sewer overflows and water pollution. A variety of storm-water controls are used in the Milwaukee and Green Bay areas. Wet and dry storm-water detention ponds of various sizes are numerous because of the low permeability of clayey surficial deposits. Combined-sewer systems (CSS) represent about 5 percent of the sewer-system infrastructure and are found mostly in the older parts of the city of Milwaukee and a few of the older suburbs. None of the sites selected for this study were part of the Milwaukee CSS. Wastewater outfalls are upstream from 6 of the 30 study sampling sites; five are in the Milwaukee area and one is in the Green Bay area. Three of the sampling sites were downstream from one wastewater outfall (Devils River, Hoods Creek, and Pike Creek); while other sampling sites had as many as 5 wastewater outfalls (three in the Menomonee River, four in Honey Creek, and five in Oak Creek).



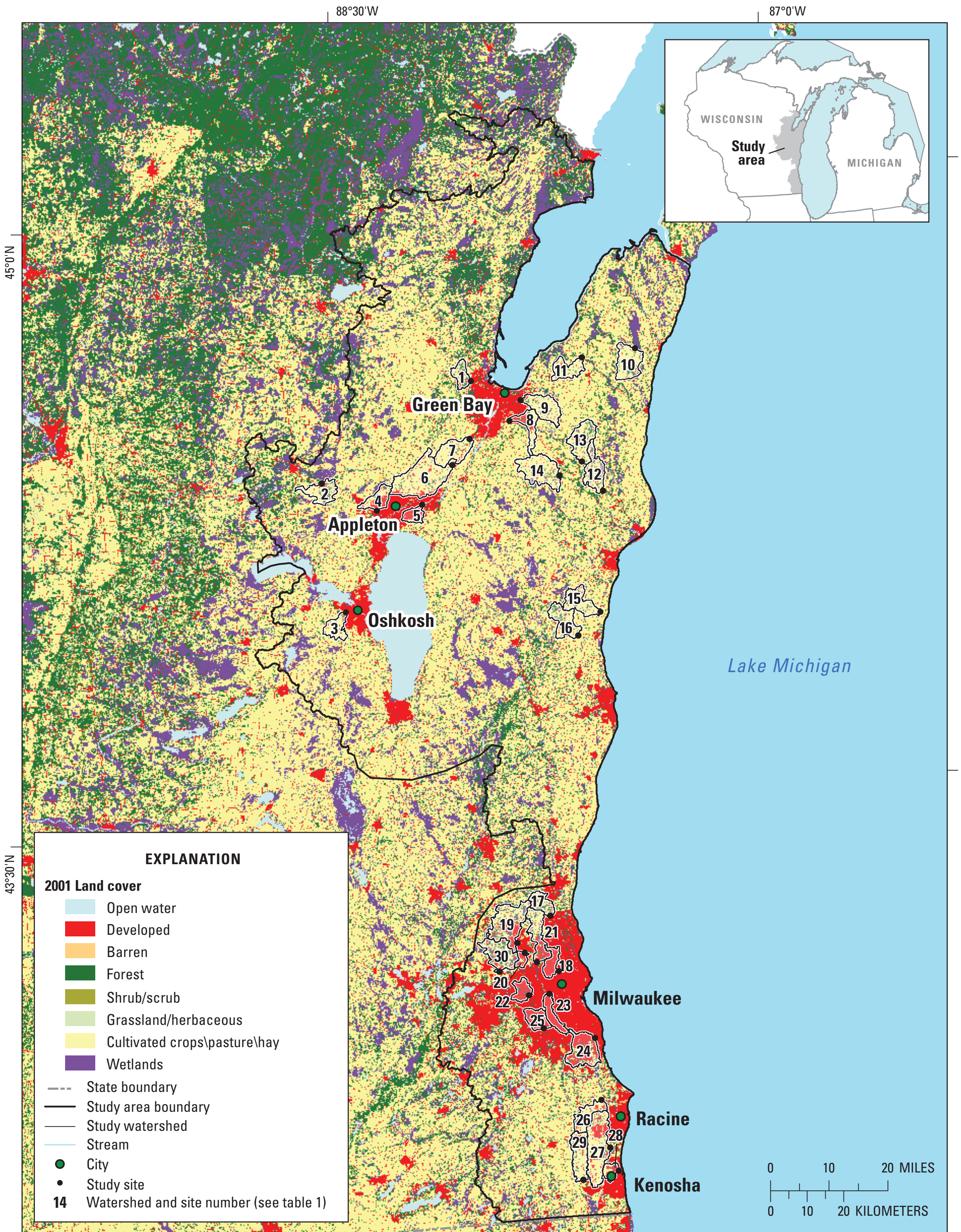
Base from U.S. Geological Survey 1:24,000 to 1:250,000 digital data, Albers Equal-Area Conic projection, NAD 83.

Figure 1. The Milwaukee to Green Bay, Wis., study area and the 30 study watersheds with Omernik's Level III ecoregions for the Milwaukee to Green Bay, Wis., study area (Omernik and others, 2000).



Base from U.S. Geological Survey 1:24,000 to 1:250,000 digital data, Albers Equal-Area Conic projection, NAD 83.

Figure 2. Surficial deposits for the 30 study watersheds in the Milwaukee to Green Bay, Wis., study area (Richmond and Fullerton, 1983, 1984).



Base from U.S. Geological Survey 1:24,000 to 1:250,000 digital data, Albers Equal-Area Conic projection, NAD 83.

Figure 3. Location and land cover for the 30 watersheds in the Milwaukee to Green Bay, Wis., study area (U.S. Geological Survey, 2006; Falcone and Pearson, 2006).

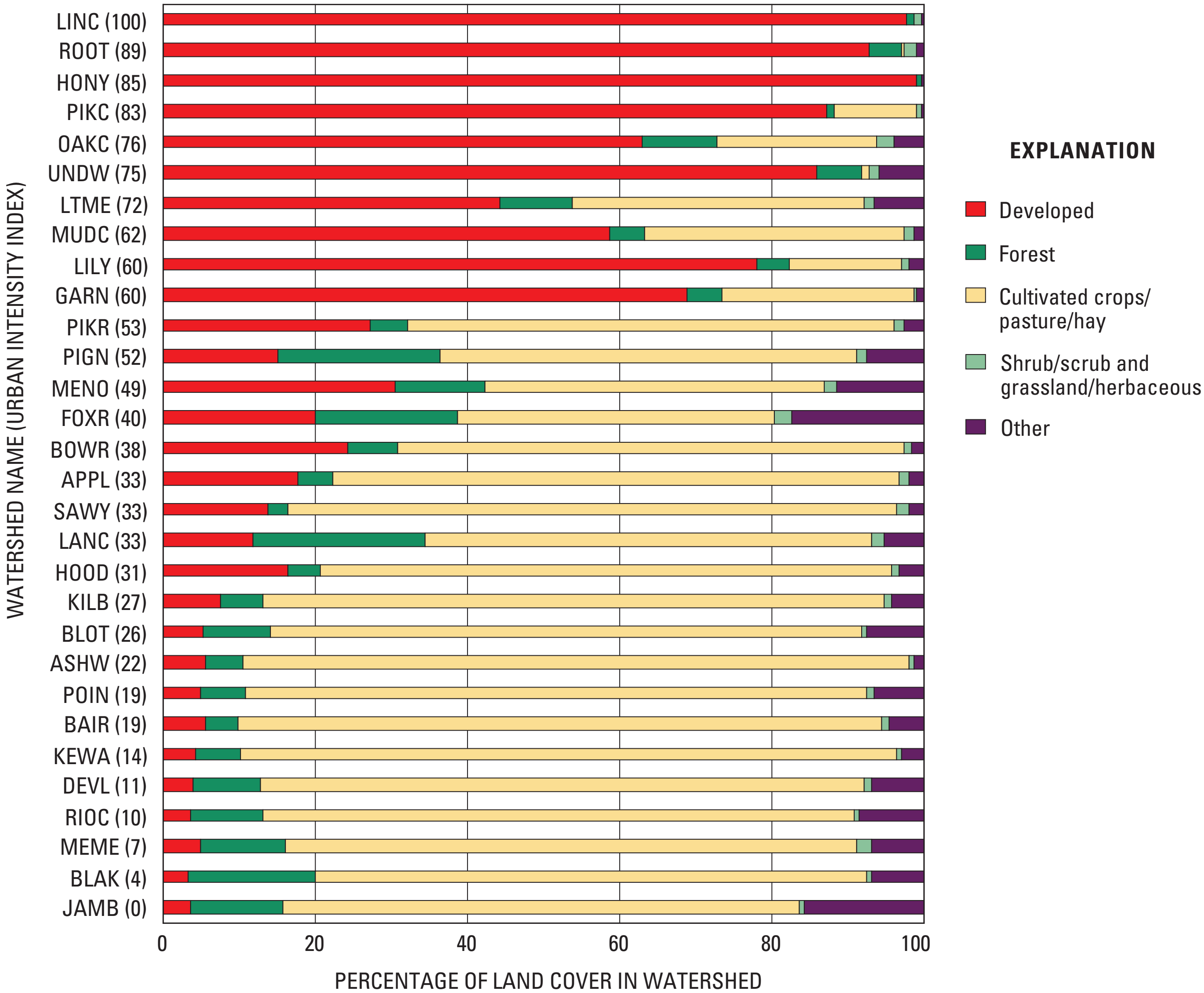
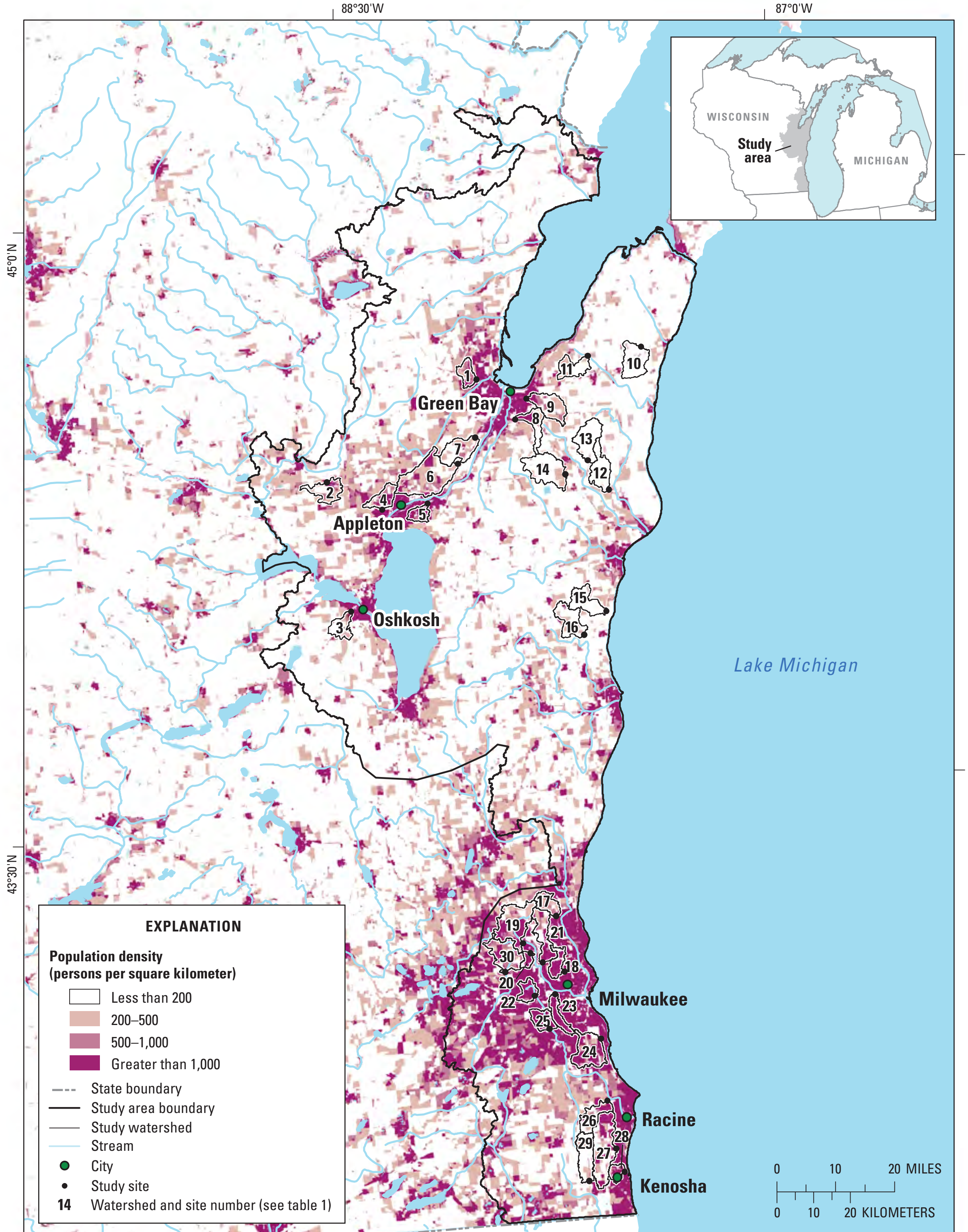
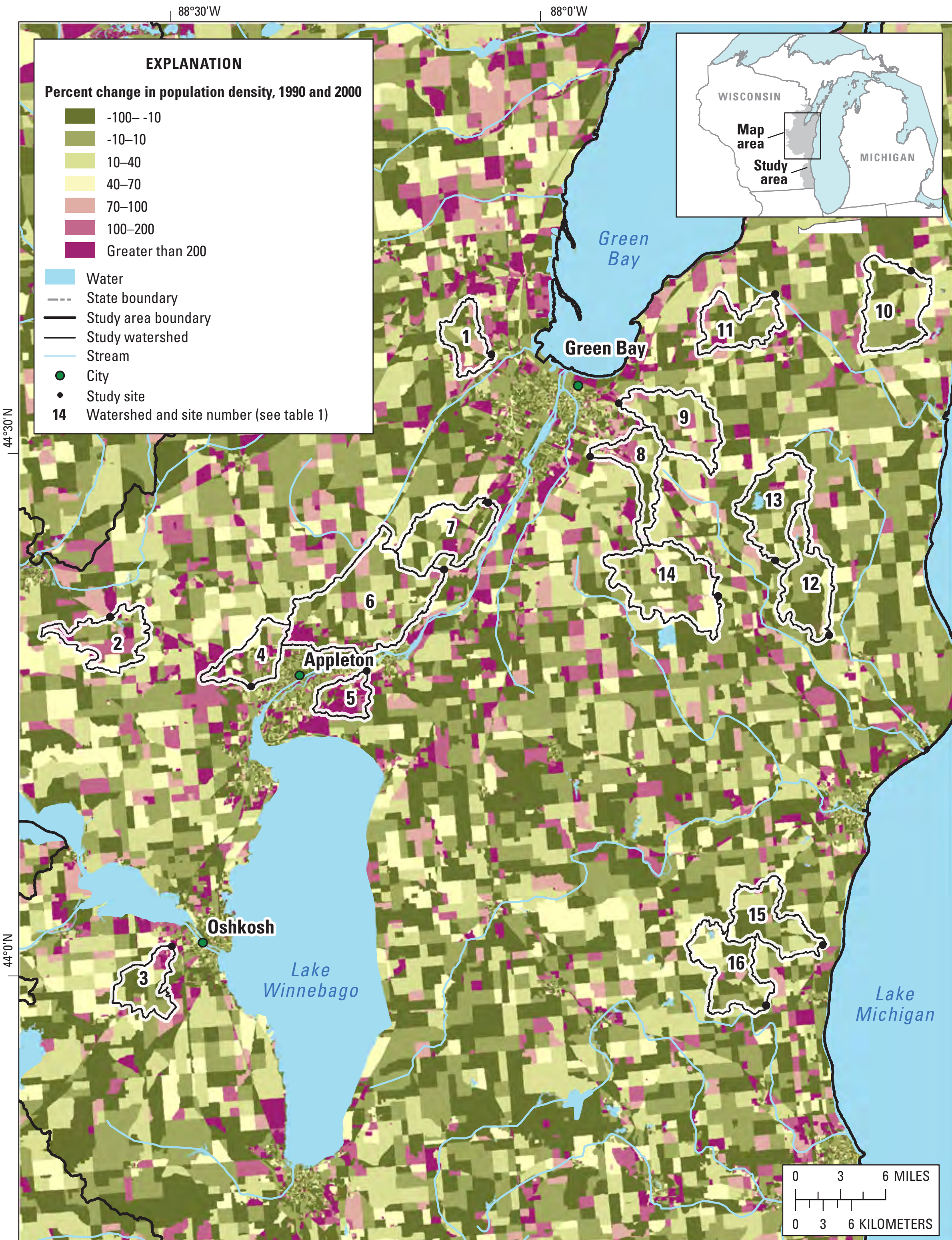


Figure 4. 2001 land-cover percentage and urban intensity index (UII) for 30 study watersheds in the Milwaukee to Green Bay, Wis., study area (U.S. Geological Survey, 2006; Falcone and Pearson, 2006).



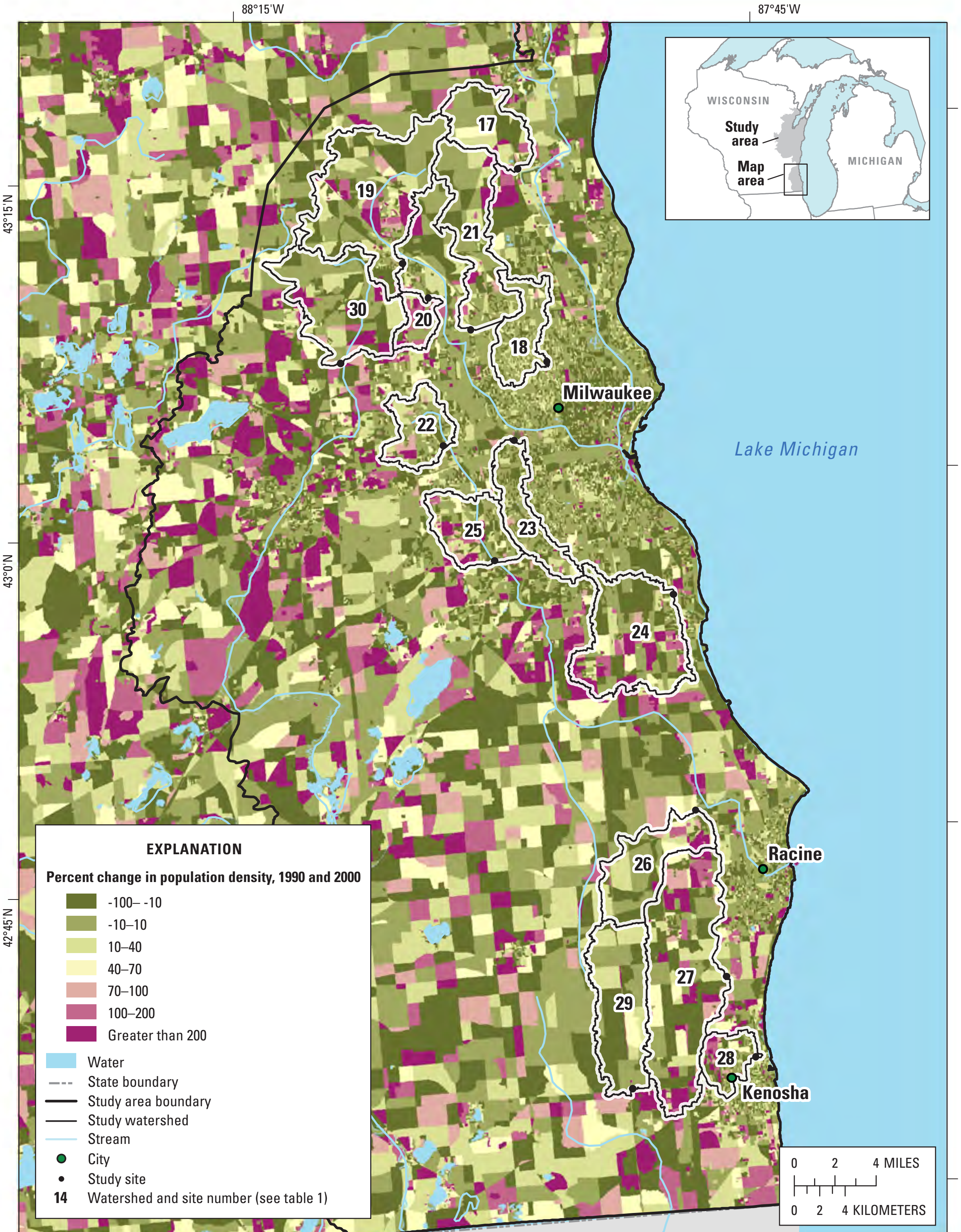
Base from U.S. Geological Survey 1:24,000 to 1:250,000 digital data, Albers Equal-Area Conic projection, NAD 83.

Figure 5. Population density derived from 2000 U.S. Census block-group data for the 30 study watersheds in the Milwaukee to Green Bay, Wis., study area (U.S. Census Bureau, 2001).



Base from U.S. Geological Survey 1:24,000 to 1:250,000 digital data, Albers Equal-Area Conic Projection.

Figure 6. Percent change in population density derived from 1990 and 2000 U.S. Census block-group data for the Green Bay, Appleton, and Oshkosh, Wis., metropolitan areas (U.S. Census Bureau, 2001).



Base from U.S. Geological Survey 1:24,000 to 1:250,000 digital data, Albers Equal-Area Conic Projection.

Figure 7. Percent change in population density derived from 1990 and 2000 U.S. Census block-group data for the Milwaukee, Racine, and Kenosha, Wis., metropolitan areas (U.S. Census Bureau, 2001).

Study Design and Site Selection, Data Collection, and Analysis

The design and data-collection methods for this study followed guidelines established for the NAWQA EUSE Study (McMahon and Cuffney, 2000; Tate and others, 2005; Falcone and others, 2007). For this study, 30 study watersheds were selected and sampled in 2003 and 2004 for an investigation of possible effects of urbanization on physical habitat, water chemistry, and aquatic biology. A geographic information system (GIS) was used to characterize the watersheds of each site. Continuous monitoring of stream stage and water temperature was conducted for each stream from October 2003 through October 2004. At each site measurements of physical habitat, water-quality parameters (nutrients, chloride, sulfate, dissolved and particulate carbon, pesticides, and suspended sediment), and collection of aquatic biota (algal, invertebrate, and fish assemblages) were made at various intervals. In addition, semipermeable membrane devices (SPMD) were deployed at each location. The data-collection methods conform to standardized USGS and NAWQA program procedures.

Study Design and Site Selection

The study design and site selection focused on three design components that included (1) minimizing variability in natural landscape features and (2) suitability of local site conditions and (3) maximizing the degree of urbanization as defined by the urban intensity index (UII) (Falcone and others, 2007). The procedure consisted of (1) defining a study area within a relatively homogeneous environmental setting, (2) characterizing the natural and urban setting of the candidate watersheds, (3) developing a multi-metric urban-intensity planning index, (4) assessing local site suitability, (5) selecting final sites, and (6) calculating a final multi-metric UII. With this information, 30 study watersheds were selected for sampling with the general methods described by Tate and others (2005).

Environmental Setting

The process began by defining a study area within a relatively homogeneous environmental setting that had little variation in natural landscape features; study watersheds could be selected across a gradient of low to high urbanization (fig. 2). Automated methods were used in conjunction with the USGS National Elevation Dataset (NED) to define 123 candidate study watersheds with drainage areas ranging from 7 to 127 km^2. The natural landscape features that define the environmental setting and the degree of urbanization within each candidate site's watershed were characterized with GIS. All GIS data sources and GIS-derived variables are listed in appendix1-1 and appendix 1-2, they are further described in Falcone and others, 2007. The set of candidate watersheds was reduced to a set of 81, using K-means clustering (Everitt and others, 2001), to identify watersheds with similar geologic and topographic characteristics.

Urban Intensity Index

An urban intensity index was developed to identify a gradient of urbanization within the candidate watersheds (McMahon and Cuffney, 2000; Tate and others, 2005; Falcone and others, 2007). The UII was developed based on GIS-derived urban characteristics that correlated strongly to population density; it was developed for the purpose of (1) planning, to identify a gradient of study watersheds from low- to high-percentage of urban land cover, and (2) analysis, to examine relations with potential response characteristics that include aquatic biota, hydrology, chemistry, and habitat (Cuffney and others, 2005; Meador and others, 2005; Potapova and others, 2005; Short and others, 2005). The 21 variables used in the UII were highly correlated with population density (Spearman's rho > 0.5) but not with watershed drainage area (Spearman's rho < 0.5); they included road infrastructure (road length, road area density, and road traffic density), density of toxic-release-inventory sites in the watershed, percentage of watershed land cover (all developed land, low-density and high-density residential, commercial and industrial land, mixed forest, pasture/hay, and urban and recreational grasses), percentage of land cover in 100-m riparian zone (developed land), and nine socioeconomic variables (U.S. Census Bureau, 2001) that characterize the watershed urban setting and the associated population's income, education, and home ownership. A field reconnaissance of candidate sites was done to determine suitability of local site conditions for sampling hydrology, biology, physical habitat, and chemistry.

Sampling-Site Suitability

During field reconnaissance, sites were evaluated for perennial flow and suitability for measuring streamflow; presence of riffle habitat; field verification of the environmental setting; adequate reach length; accessibility and safety for sampling; and identification of point sources, outfalls, bridges, and dams that could impact sampling results. It was necessary for site reaches to contain rock riffles to minimize potential variations in invertebrate populations caused by sampling multiple substrate types.

Site Selection

An iterative process was used to select the final 30 watersheds. Watershed boundaries for the 30 sites were refined based on NED, topographic maps, and field reconnaissance. A GIS was used to recalculate natural landscape and urbanization characteristics; the UII was also recalculated, using the methods described earlier for the planning UII that used the updated GIS-derived watershed characteristics. The 35 variables used in the final UII represented the major categories of urbanization and included road infrastructure (road area index and road traffic index), riparian land cover (percentage of impervious surface, shrubland, and agriculture), watershed land cover (percentage of impervious surface, developed land, shrubland, and agriculture) and 26 socioeconomic variables (U.S. Census Bureau, 2001) that characterized the urban setting and population. Variables selected for the UII were highly correlated with 2000 population density and percentage of impervious surface (Spearman's rho>0.5) (fig. 8); they were not highly correlated with drainage area (Spearman's rho <0.5). The UII values for the 30 sites ranged from 0 to 100, as a result of standardization; however, a higher proportion of the sites selected were at the lower end of the UII scale (table 1) (fig. 9) as part of the study design. Selected study sites were weighted toward the lower end of the UII scale for the purpose of having a larger sample size of sites that fall within the 10- to 25-percent range where previous studies have identified effects from urbanization on stream ecosystems. Of 30 study sites, the UII values of 17 sites were less than 40; there were fewer than 200 people/km^2 and less than 10 percent impervious surface in those watersheds.

Ecoregions and texture of surficial deposits were primary characteristics used to constrain site selection. The structures of many biological assemblages have been found to correlate with ecoregions, and the texture of surficial deposits is known to influence the response of aquatic ecosystems to urbanization, as reported in other Midwest urbanization studies (Harris and others, 2005). All selected study watersheds were thought to have fine-textured surficial deposit, based upon STATSGO soils. Upon further investigation, however, two of 30 sites (Fox and Menomonee Rivers) were found to have less than 25 percent watershed clayey surficial deposits, based on Wisconsin glacial geology maps. The discrepancy in the two spatial-data layers may have influenced the results of this study through site selection; the discrepancy points to the importance of closely evaluating the GIS spatial-data layers used to constrain site selection.

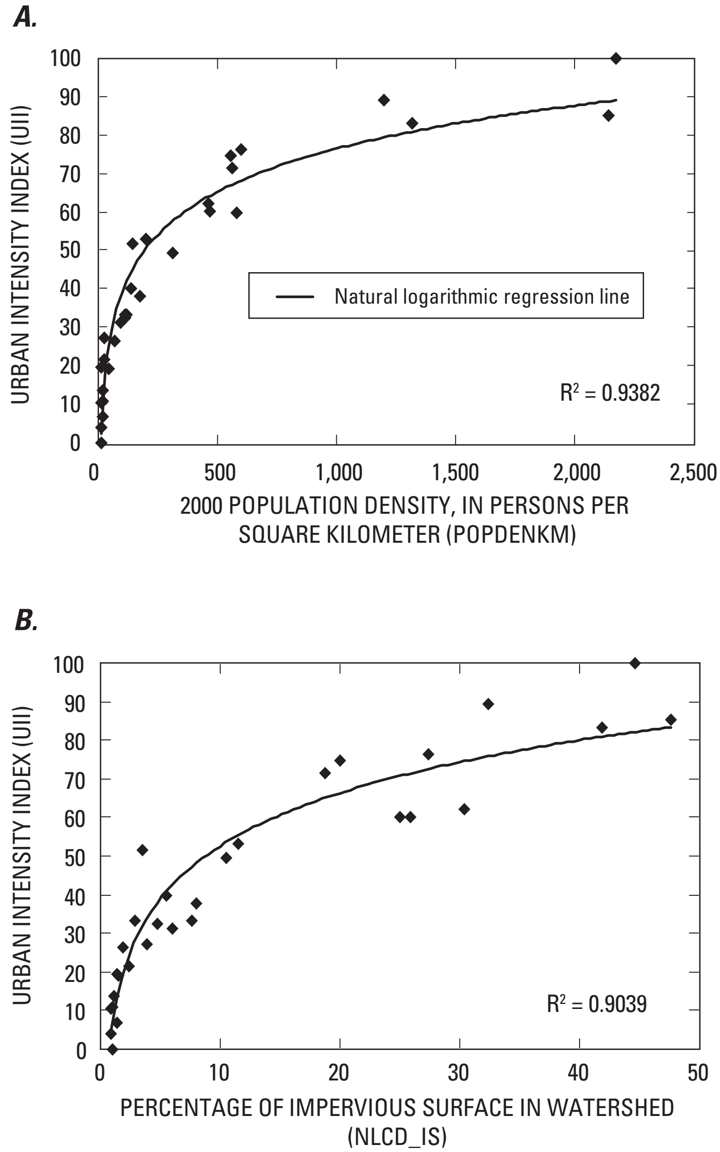
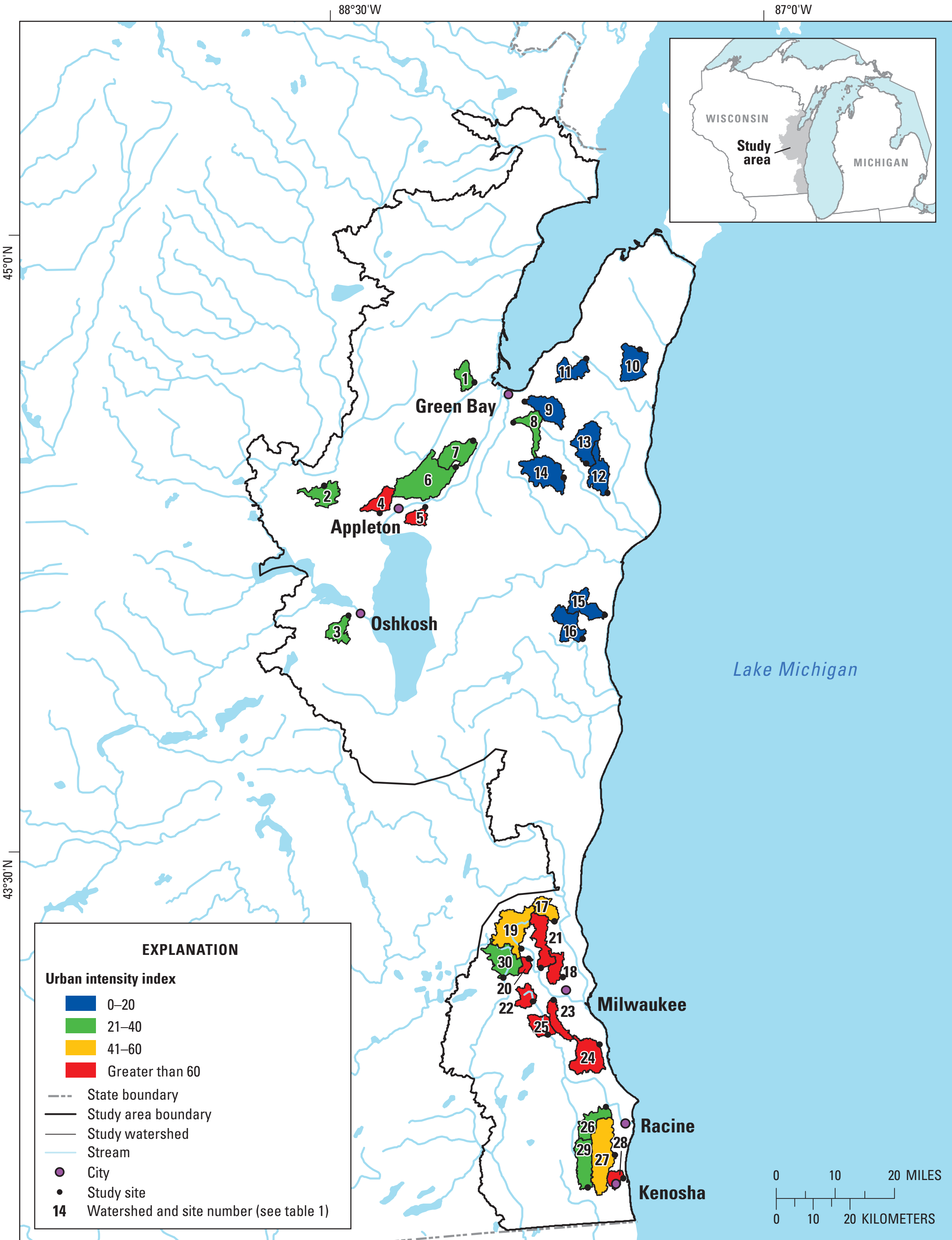


Figure 8. Relations between urban intensity index, and *A*, 2000 population density (U.S. Census Bureau, 2001), and *B*, percentage of impervious surface in watershed for 30 study watersheds in the Milwaukee to Green Bay, Wis., study area (Falcone and Pearson, 2006).



Base from U.S. Geological Survey 1:24,000 to 1:250,000 digital data, Albers Equal-Area Conic projection, NAD 83.

Figure 9. Location and urban intensity index values (McMahon and Cuffney, 2000) of the 30 study watersheds in the Milwaukee to Green Bay, Wis., study area.

Data-Collection Methods

Data collection methods for habitat, water chemistry, and biological characteristics followed standardized procedures used by the NAWQA program. These methods are described briefly below. Data for each site are available at the NAWQA Data Warehouse (http://infotrek.er.usgs.gov/traverse/f?p=NAWQA:HOME:1556904759732651). Measurements of stream stage at 22 sites with pressure transducers and measurement of potential toxicity with SPMD's used nonstandard methods; these methods are described in more detail below.

Habitat

Reach-scale habitat assessments were conducted in August 2004 during low flow following NAWQA protocols (Fitzpatrick and others, 1998) (table 2, appendix 1-4). Data included qualitative and quantitative measurements of riparian, channel, flow, substrate, and bank characteristics at 11 transects distributed equally along the reach; data also were collected at five points (two bank and three in-stream) along each transect.

Dominant riparian land cover within a 30-m riparian zone was recorded for each transect endpoint. The percentage of endpoints with disturbed riparian land cover was calculated for each reach. Disturbed land cover included cropland, pasture, farmsteads, residential, commercial, and transportation. Undisturbed land cover was considered to be grassland, shrubs and woodland, and wetland. The open canopy angle was measured at the center of each transect and the riparian canopy closure was measured for each transect endpoint.

Channel measurements included the identification of channel geomorphic units (riffles, runs, and pools), water-surface slope, bankfull-channel dimensions, and wetted-channel dimensions. Two geomorphic channel-unit indexes were calculated, using a pool-to-riffle ratio and also a run-to-riffle ratio because pools were present only at 10 of the 30 sites. Morphologic indicators were used to estimate bankfull stage and included variations in bank slope and riparian vegetation, undercut banks, and substrate changes associated with point bars (Fitzpatrick and others, 1998). Reach-averaged bankfull dimensions were compared for all geomorphic-channel units and for riffle/runs only. Bankfull dimensions were normalized by drainage area. Bankfull shear stress was calculated from bankfull-hydraulic radius and slope. Critical particle size (D_{50}) for incipient motion was calculated using the Shields equation, bankfull-hydraulic radius, and slope.

Wetted dimensions were used to calculate a channel-shape index and shape variability. The channel-shape index (ChShp) was calculated for each transect by the equation (Armantrout, 1998):

$$ChShp=(W/D)^{(D/Dmax)}, \qquad (1)$$

where

W is wetted width;

D is average depth; and

Dmax is maximum depth.

Smaller values of ChShp indicate narrow/deep or pool-like conditions; larger values indicate more wide/shallow or riffle-like conditions. This index provides a measure of relative occurrence of macro-habitat conditions (Terry Short, U.S. Geological Survey, written commun., 2003). The coefficient of variation of channel shape provides a measure of habitat variability. A channel-stability index also was calculated by dividing the average bankfull channel area by the wetted cross-sectional area.

Velocities were measured at each transect point and used to calculate a Froude number that represents the availability of pool habitats and general flow conditions. Roughness also was calculated.

Presence/absence of instream habitat cover for fish, including woody debris, was recorded at each of three in-channel points along transects. In shallow streams, cover in less than 0.3 m of water was not considered habitat cover. Water depths were less than 0.3 m in many sites because of the small drainage areas. Habitat-cover values were anomalously low in these streams, and the data have limited use for comparison to biotic communities. Data for percentages of habitat cover were not used in analyses for this report.

Observations of dominant streambed substrate size were summarized into an index that gives more weight to smaller-size classes, typical for midwestern streams (Terry Short, U.S. Geological Survey, written commun., 2003). Average percentage of embeddedness was calculated and presence/absence of loose silt was recorded. A streambed-substrate-stability index was calculated by dividing the substrate particle size by the critical particle size at bankfull flow (Kaufmann and others, 1999).

Bank vegetative cover, angle, substrate, and presence/absence of erosion were measured at each transect endpoint. In addition to the protocol requirements, the length of bare ground along the bank was measured.

Table 2. Selected habitat characteristics used to determine urbanization effects on habitat for 30 sites in the Milwaukee to Green Bay, Wis., study area.

[%, percent; m, meter; m/km^2, meter per square kilometer; N/m^2, newtons per square meter; mm, millimeter; m^2/km^2, square meter per square kilometer; m^3, cubic meter; m^3/s, cubic meter per second; (m^3/s)/km^2, (cubic meter per second) per square kilometer]

Characteristic abbreviation	Characteristic definition (units)	Mean	Minimum	Maximum
	Riparian vegetation			
RipLU	Disturbed land cover in 30-m buffer (%, out of 22 transect endpoints)	60	0	100
OCanAngleAvg	Mean open-canopy angle (degrees)	44	5	144
	Channel geomorphology			
WaterSurfGradPct	Reach water-surface gradient/slope (%)	.34	.02	1.08
BFWidthAvg	Mean bankfull channel width (m)	7.8	3.4	13.3
BFWidthNoPools	Mean bankfull channel width (excluding pools) (m)	7.5	3.2	13.3
BFWidthDA	Mean bankfull width divided by drainage area (excluding pools) (m/km^2)	.19	.09	.48
BFDepthAvg	Mean bankfull depth (m)	.7	.5	1.2
BFDepthNoPools	Mean bankfull depth (excluding pools) (m)	.7	.5	1.2
BFShear	Mean bankfull shear stress (N/m^2)	23	2	84
BFDepthDA	Bankfull depth divided by drainage area (excluding pools) (m/km^2)	.02	.01	.05
BFWidthDepthAvg	Mean bankfull channel width-depth ratio (with pools)	11.1	5.1	21.7
BFWidthDepthNoPools	Mean bankfull channel width-depth ratio (excluding pools)	10.9	4.8	21.0
BFArea	Mean bankfull channel cross-sectional area (m^2)	5.9	2.3	15.5
BFAreaNoPools	Mean bankfull channel cross-sectional area (excluding pools) (m^2)	5.5	2.1	15.5
BFAreaDA	Mean bankfull channel cross-sectional area divided by drainage area (m^2/km^2)	.15	.06	.34
BFAreaNoPoolsDA	Mean bankfull channel cross-sectional area divided by drainage area (excluding pools) (m^2/km^2)	.14	.06	.34
$BFD_{50}crit$	Critical particle size (mm) for incipient motion (hydraulic radius (m) × slope (ratio) × 13.7 × 1,000 mm/1-m)	32	3	117
GCUTypeRiffPct	Relative proportion of the total length of all geomorphic channel units that are comprised of riffles (%)	22	2	40
GCUTypePoolPct	Relative proportion of the total length of all geomorphic channel units that are comprised of pools (%)	12	0	39
GCUTypeRunPct	Relative proportion of the total length of all geomorphic channel units that are comprised of runs (%)	66	45	95
GCUTypePoolRiff	Ratio of the area of pool geomorphic units to the area of riffle geomorphic channel units	.7	.0	6.4
GCUTypeRunRiff	Ratio of the area of run geomorphic units to the area of riffle geomorphic channel units	5.7	1.3	47.1
DepthAvg	Mean wetted-channel depth (m)	.25	.11	.56
DepthMax	Maximum wetted-channel depth (m)	.66	.32	2.00
DepthCV	Coeffiecient of variation of wetted-channel depth (m)	61.1	34.6	96.4
RchVol	Reach wetted channel volume = reach length multiplied by mean channel width multiplied by mean depth (m^3)	241.9	63.1	646.2
HydRadAvg	Mean wetted-channel hydraulic radius (m)	.24	.11	.50
WidthDepthAvg	Mean wetted-channel width-depth ratio	31.7	13.4	65.0
WetXAreaAvg	Mean cross-sectional area of wetted channel (m^2)	1.7	.5	4.4

Table 2. Selected habitat characteristics used to determine urbanization effects on habitat for 30 sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[%, percent; m, meter; m/km^2, meter per square kilometer; N/m^2, newtons per square meter; mm, millimeter; m^2/km^2, square meter per square kilometer; m^3, cubic meter; m^3/s, cubic meter per second; (m^3/s)/km^2, (cubic meter per second) per square kilometer]

Characteristic abbreviation	Characteristic definition (units)	Mean	Minimum	Maximum
	Channel morphology (continued)			
ChStab	Channel stability = ratio of mean bankfull to wetted cross-sectional areas	4.2	2.0	12.1
ChShpCv	Coefficient of variation of wetted channel shape index	161	35	96
Froude	Froude number = mean flow velocity divided by square root of (acceleration due to gravity multiplied by mean depth of water) (dimensionless)	.06	.00	.22
	Flow characteristics			
VelocAvg	Mean velocity at the time of habitat sampling (m/s)	.09	.00	.34
DischM3Sec	Instantaneous discharge at time of habitat sampling (m^3/s)	.10	.00	1.12
DischargeDA	Discharge at the time of habitat sampling divided by drainage area ((m^3/s)/km^2)	.002	.000	.022
	Streambed substrate			
BedSubMedian	Median dominant streambed substrate, calculated as D_{50} (mm)	44	.031	192
FinesPct	Occurrence of transect points where the dominant substrate consists of particles that are less than 2 mm (%)	24	0	64
DomSub3Pct	Occurrence of transect points where the dominant substrate consists of sand (>0.062–2 mm) (%)	14	0	46
SiltCovPct	Occurrence of transect points where a silt layer was observed on streambed (%)	74	0	100
BedSubIndex[1]	Streambed substrate index—square-root differences of relative particle size categories	2.5	.7	5.7
BedSubStab[2]	Streambed substrate stability index—competence, incipient motion, based on Shield's criteria. D_{50}/D_{50} critical. D_{50} critical is based on bankfull hydraulic radius and slope	1.3	.01	5.1
EmbedPctAvg	Mean embeddedness (%)	58	31	90
	Bank characteristics			
BankErosPct	Occurrence of banks with erosion (presence/absence) (%)	91	59	100
BankVegCovAvg	Mean bank vegetative cover (%)	39	9	89
BankSubAvg	Mean bank substrate type[3] (category)	2.7	2.0	7.0
ErosionLengthAvg	Mean bank erosion length, average (m)	1.5	.1	3.6

[1] Terry Short, U.S. Geological Survey, written commun., 2003.

[2] Kaufmann and others, 1999.

[3] Bank substrate types from Fitzpatrick and others (1998):

Description	Category number
Smooth bedrock/concrete/hardpan	1
Silt, clay, marl, muck, organic detritus	2
Sand (>0.063–2 mm)	3
Fine/medium gravel (>2–16 mm)	4
Coarse gravel (>16–32 mm)	5
Very coarse gravel (>32–64 mm)	6
Small cobble (>64–128 mm)	7
Large cobble (>128–256 mm)	8
Small boulder (>256–512 mm)	9
Large boulder, irregular bedrock, irregular hardpan, irregular artificial surface (>512 mm)	10

Hydrology

Pressure transducers with an internal data logger and a range of 0 to 30 m were used to measure stream-stage fluctuation, October 1, 2003 through October 30, 2004. The precision of stage data from the pressure transducer is ±3.6 cm, which does not meet USGS requirements for the precision of stage data (±0.3 cm) (Sauer, 2002). The pressure transducers were installed prior to chemical and biological sampling at 22 of the 30 sites; standard USGS streamflow-gaging station site equipment was in place at the remaining 8 sites. Pressure transducer stage was measured relative to an arbitrary datum and recording intervals were set to 15 minutes. To prevent ice-related damage, the pressure transducers were removed during the winter at all but six sites; water depth at these six sites was sufficient to prevent ice damage to the pressure transducers. Removal of pressure transducers because of ice conditions and limited intermittent instrumentation failure at these sites necessitated separating the hydrologic-condition metric data into two time periods. Pre-ice (October 1–December 8, 2003) and post-ice (March 16–October 30, 2004) interval metrics were calculated for data where at least 80 percent of hourly timesteps were available. The pre-ice period was 70 days, with 22 sites analyzed; the post-ice was 228 days, with 24 sites analyzed.

This pressure transducer model was unvented; that is, there was no vent tube to offset change in atmospheric pressure. Changes in stage were recorded as a result of water-level changes and atmospheric-pressure changes. As a result, the data were corrected for fluctuations in atmospheric pressure by using hourly barometric-pressure data from nearby airports (continuous barometric-pressure records were not available at the study sites). The airport data were matched to the shorter 15-minute timestep of the pressure-transducer data through linear interpolation between the hourly atmospheric-pressure readings. Because a difference in altitude between the airport and the study site potentially could create a difference in ambient barometric pressure between the two locations, the following equation was used to determine barometric pressure at the study site from the corresponding barometric pressure at the airport:

$$h = \frac{T * 287 * \ln(\frac{P_0}{P_1})}{9.8} \quad (2)$$

where

h is the difference in altitude between the airport and the study site (in meters);

T is the average temperature of the layer of the atmosphere, assumed from the ambient airport temperature (in Kelvin);

P_0 is the station pressure of the airport or site, whichever is at the lower altitude (in millibars); and

P_1 is the station pressure of the airport or site, whichever is at the higher altitude (in millibars).

After the barometric-pressure correction was completed, the last stage reading in each pressure-transducer data file was compared to the concurrent stage reading taken manually from a fixed external point during each site visit; deviation from this external stage reading indicated the occurrence of instrument drift since the time of calibration. When deviations were found, a prorated correction was applied to all of the stage data recorded by the pressure transducer between the first and last logs in the file (Sprague and others, 2006).

A pressure transducer was paired with a conventional USGS streamflow-gaging station at Honey Creek at Wauwatosa (04087719) (fig. 10). The flow oscillation in the pressure-transducer record is a result of approximately 1-cm stage oscillations in the pressure-transducer stage record.

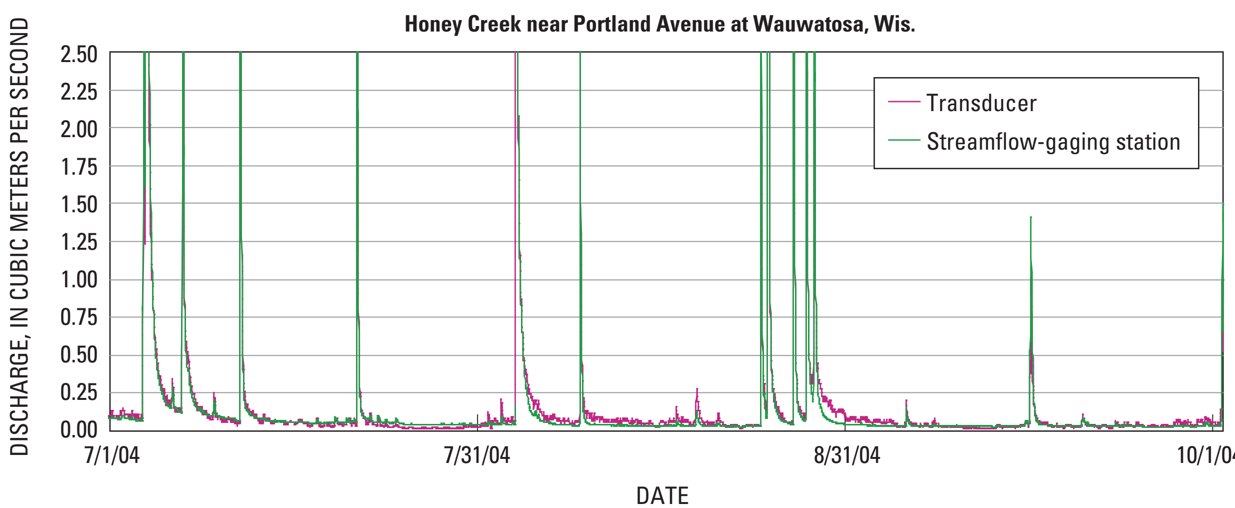


Figure 10. Comparison of discharge record from the U.S. Geological Survey streamflow-gaging station (04087119) and the record from the pressure transducer (04087118) at the Honey Creek near Portland Avenue at Wauwatosa, Wis., site (Waschbusch and others, 2005).

Pressure-corrected pressure-transducer data were within the 3.6-cm documented precision (Sprague and others, 2006). Although these stage and resulting flow data do not have the level of accuracy normally seen from conventional USGS stage data, they are acceptable for the purposes of this study.

Stream Temperature

Temperature data were collected at 15-minute intervals with thermisters attached to pressure transducers used to measure stream-stage data. Temperature data were verified in the field on 89 occasions, using a National Institute of Standards and Technology traceable thermometer (Control Company traceable thermometer, model number 4000) in conjunction with water-quality-data collection.

Water Chemistry

Water samples were collected for chemical analysis between November 2003 and September 2004. An exception was at one site where, because of zero flow, a change of sites was necessary; a single sample was collected in May 2005. All samples were collected, processed, filtered, and preserved on site, following protocols outlined in the USGS National Field Manual for the Collection of Water Quality Data (U.S. Geological Survey, variously dated). Water samples were collected twice at all sites—once during elevated flow (Q10-Q50) conditions in late spring (mid-May to early June 2004) and again at base-flow conditions (Q90) during ecological sampling in summer (August–September 2004). The summer chemistry data were considered reflective of water-quality conditions that would have immediate impact on biological communities at the sites. At a subset of 10 sites designated as “higher intensity sites,” four additional water-chemistry samples were collected during the year at a variety of flow conditions, including under ice cover. The high-intensity site samples were collected to register the seasonal responses of water chemistry. The 10 high-intensity sites selected covered the range of urban land cover, with urban intensity scores from 4 to 100.

Samples were analyzed for concentrations of the constituents shown in appendix 1-6. Field measurements of pH, alkalinity, specific conductance, dissolved oxygen, and air and water temperature were collected. Prior to water-quality samples being collected, discharge measurements were made at sites without established stage/discharge relations, following established USGS procedures described in Rantz and others (1982). Suspended-sediment samples were analyzed at the USGS Missouri Water Science Center Sediment Laboratory, using methods described in Guy (1969). The remaining chemical analysis was done by the USGS National Water Quality Laboratory (NWQL) in Lakewood, Colo., using methods described in Fishman and Friedman (1989), Brenton and Arnett (1993), Fishman (1993), Zaugg and others (1995), U.S. Environmental Protection Agency (USEPA) (1997), Sandstrom and others (2001), and Patton and Kryskalla (2003). Field quality-control samples were collected throughout the study period and included field blanks and sample splitter replicates.

Semipermeable membrane devices (SPMDs) are passive samplers for assessing trace levels of hydrophobic organic contaminants. SPMDs are designed to mimic biological membranes, such as the gills of fish. SPMDs contain a thin film of neutral lipid (triolein), enclosed in thin-walled lay-flat tubing made of low-density polyethylene polymer; the 10-angstrom-diameter cavities allow select diffusion of organic contaminants, specifically polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), organochlorine and pyrethroid insecticides (Huckins and others, 1993). SPMDs, when deployed in a stream, passively accumulate hydrophobic organic contaminants just as aquatic biota do and readily concentrate contaminant residues that are metabolized by many aquatic biota (Huckins and others, 1993). Two 6-in SPMDs were placed at each stream site for approximately 30 days beginning in mid-July 2004. Water-quality measurements (including water temperature, dissolved oxygen, conductivity, and pH) were taken at deployment and retrieval. A spot-velocity measurement was taken at deployment and retrieval using a standard USGS pygmy current meter.

Following retrieval, the SPMDs were shipped to Environmental Sampling Technologies in St. Joseph, Mo., where the contaminants were extracted from the lipids in an organic solvent; dialysis methods described in Huckins and others (1990) were used. Three assays were run on the SPMD extracts—two at the USGS Columbia Environmental Research Center (CERC) in Columbia, Mo., and one at the U.S. Army Corps of Engineers (USACE) Environmental Laboratory in Vicksburg, Miss. The Microtox bioassay (Johnson, 1997, 1998) and the ultraviolet fluorescence scan (Johnson and others, 2004) were run at the CERC. Microtox bioassay measures the light production of photo-luminescent bacteria when exposed to the SPMD extract; a number of the compounds sequestered by the SPMDS had lower light production. Microtox bioassay results are reported as EC50, the concentration of the SPMD extract that caused a 50-percent reduction in light production. The next assay, the ultraviolet fluorescence scan, provides a semi-quantitative screening for PAHs (which fluoresce under ultraviolet light). Different concentrations of pyrene (a PAH compound) are used to develop a standard curve, using a specific wavelength of ultraviolet light. The SPMD extract is exposed to this same specific wavelength of ultraviolet light, and the results are reported as pyrene index in milligrams per SPMD (mg/SPMD) extract. The Cytochrome P450 Reporter Gene Systems (P450RGS) (Murk and others, 1996) assay was done at the USACE Environmental Laboratory. The P450RGS assay is a screening tool for aryl hydrocarbon receptor (AhR) type compounds that include PCBs, PAHs, dioxins, and furans.

All vertebrates produce detoxifying enzymes upon exposure to AhR compounds; the amount of enzymes produced is directly proportional to the concentration of the compounds. Quantifying one of these enzymes (the gene Cytochrome P450 1A1 or CYP1A1) serves as a measure of dioxin activity. The concentration of AhR compounds in the SPMD extract that induces CYP1A1 production is expressed as the amount of dioxin, in toxic equivalents (TEQs), that would induce the same response (Sprague and others, 2006). Extract from each SPMD was sent to the NWQL for analysis. Analytical methods for the extract are described in detail in Sprague and others (2006).

The SPMD from Ashwaubenon Creek near Little Rapids, Wis., was lost during shipment to the USACE laboratory. Also, SPMD data were not available for Apple Creek near Sniderville; this site was a replacement site because of zero flow during ecological sampling at another site. Quality-control samples included laboratory blanks (dialysis and solvent) and trip blanks. Laboratory blanks were collected to monitor for possible manufacturing and laboratory contamination. Two trip blanks were collected and exposed to the atmosphere at each site during deployment and retrieval of the SPMD. The blank canister was opened at the same time as the deployed SPMD canisters; the blank canister was sealed after the field SPMD was deployed. Each trip blank's canister was marked for each site at which it was exposed for quality assurance. Each trip blank was exposed to the same airborne environmental contamination as the field SPMDs during deployment and retrieval. Replicate SPMDs were deployed at three sites—Pike Creek, Little Menomonee River, and Meeme River.

Biology

Algal, invertebrate, and fish assemblage data were collected one time at each of the 30 study sites. Fish assemblage data were collected during July 2004; algal and invertebrate assemblage data were collected during August–September 2004.

Algae

At each stream, two contrasting habitats were sampled that were estimated to be the primary periphyton habitats in the study sites, the depositional-targeted habitat (DTH) and the taxonomically richest-targeted habitat (RTH). The NAWQA DTH and RTH sampling method was used for this study because the surface area sampled by this method is quantifiable and those two habitats are generally where periphyton growth dominates in streams (Porter and others, 1993; Moulton and others, 2002).

For the RTH sample, five cobbles or large gravel rocks were collected at five locations in each stream, for a total of 25 composited subsamples as described in Porter and others (1993) and Moulton and others (2002). The RTH sample was collected by using the SG-92 periphyton sampler that has a consistent, measurable area. The sampling device was placed on the surface of the cobble; the periphyton within the perimeter were removed by adding small amounts of filtered stream water, brushing the cobble exposed inside the SG-92, and pipetting the water and loosened algae into the 500-ml plastic sample bottle. This was repeated several times to remove all periphyton attached to the cobble within the area of the sampling device. When all subsamples were taken, the composited sample was mixed and subsampled for analysis of chlorophyll *a* (Arar and Collins, 1997) and ash-free dry mass (Britton and Greeson, 1987) at the USGS NWQL. The volume of the remaining sample was determined by pouring the sample into a graduated cylinder. The remaining sample was returned to the sample bottle and preserved with buffered (pH 7) formalin up to 5 percent of the sample volume for identification at the Academy of Natural Sciences in Philadelphia, Penn. (Charles and others, 2002).

For the DTH sample, subsamples were collected from fine sediment such as silt and clay at five discrete locations in each stream and composited as described in Porter and others (1993) and Moulton and others (2002). DTH subsamples were collected by inverting the lid of a plastic 4.7-cm petri dish onto the streambed sediment. Each subsample was removed by slipping a plastic spatula under the lid, lifting it from the substrate and removing additional sediment not contained under the lid. The subsample then was washed with filtered stream water into a 500-ml plastic bottle. After all five DTH subsamples were composited, the volume of the sample was determined by pouring the sample into a graduated cylinder. The sample was returned to the sample bottle and preserved with buffered (pH 7) formalin up to 5 percent of the sample volume for identification and enumeration at the Academy of Natural Sciences in Philadelphia, Penn. (Charles and others, 2002).

Invertebrates

One quantitative and one qualitative benthic-macroinvertebrate assemblage sample was collected at each site. Samples were collected and processed following USGS protocols; sampling was concurrent with algal and habitat sampling (Moulton and others, 2002). The quantitative (RTH) sample was collected from riffles with disturbance-removal sampling. The standard NAWQA sampler, the Slack sampler, is a rectangular frame net (50 × 33 cm) fitted with 500-µm mesh ($0.25m^2$). Five discrete subsamples were collected and composited for a single sample from each stream. At each of the five subsample locations, water depth and velocity measurements were made, and substrate type and percentage of embeddedness were recorded. Ideally, the five samples were from two riffles; more or fewer riffles were sampled, depending on availability. Specific subsample locations were chosen to reflect a variety of riffle positions (top, middle, bottom, and lateral).

The qualitative multi-habitat (QMH) sample from each reach was collected from multiple instream habitats. Instream-habitat types were identified, and the sampling effort was standardized by a 1-hour time limit; equal collection time for each habitat was spent. Collections were made with a 500-µm mesh ($0.25m^2$) D-frame kick net; these were supplemented with hand-picked collections from various substrates (for example, cobbles, woody debris, leaf packs).

All samples were processed in the field to remove large debris (leaves, twigs, filamentous algae) and inorganic debris (mostly sand). Samples were preserved in buffered (pH 7) formalin at 10 percent of the sample volume and sent to the USGS NWQL for sorting and identification.

The USGS NWQL Biology Unit sorted the invertebrate samples, using a 500-organism count method; organisms were identified according to Moulton and others (2000). When possible, mollusks, crustaceans, and insects were identified to either species or genus, and other benthic-macroinvertebrate groups were identified to higher taxonomic levels.

Fish

Fish assemblages were sampled using nationally consistent methods for the USGS NAWQA Program (Meador and others, 1993; Moulton and others, 2002). Sampling was done by electrofishing with either backpack or towed-barge units for an approximately 150-m reach at each site; two electrofishing passes were made for each stream reach. In addition, three seine hauls were made in each reach with 6.4-mm. mesh nets. Collected fish were identified to species, counted, weighed, and measured for total length before being released back to the stream. For fish whose species identification could not be confirmed in the field, several individuals were archived in buffered (pH 7) formalin at 10 percent of the sample volume and identified later by taxonomists.

Fish-assemblage data for Apple Creek near Sniderville were collected in mid-July 2004 by Tim Ehlinger of the University of Wisconsin–Milwaukee, using similar methods. Apple Creek was a replacement site for an earlier site that had zero flow during USGS ecological sampling; no USGS fish data were available for this site.

Analysis of Physical, Chemical, and Biological Data

Physical and chemical data together with biological community data and metrics were analyzed to determine their relations to the UII and individual measures of urbanization. Relations between biological assemblages and environmental characteristics also were examined.

Statistical Methods

A combination of methods including non-parametric Spearman rank correlation, x-y scatterplots, and multivariate ordination techniques were used initially to examine relations between biological assemblages and environmental characteristics and to reduce the number of collinear characteristics for subsequent multivariate analyses. Spearman's rho is a nonparametric correlation coefficient that is computed by calculating Pearson's r on the ranks of the original data (Iman and Conover, 1983; Helsel, 2004). For individual correlations, the critical rho values for 30 sites were 0.362 for a p-value of 0.05, 0.467 for a p-value of 0.01, and 0.580 for a p-value of 0.001. The Bonferroni adjustment is an adjustment where the significance level of a statistical test is adjusted to protect against Type I errors when multiple comparisons are being made. The Bonferroni adjustment divides the confidence interval (p-value = 0.05) by the number of tests. For correlations, the critical rho values for physical and chemical variables were habitat (0.66), pre-ice hydrology (0.67), post-ice hydrology (0.64), water chemistry (0.68), and SPMDs (0.73) for a p-value of 0.05. Any mention of significant correlations in this report refers to Bonferroni-adjusted data, except where noted. All data analysis was done in Data Desk version 6.1 (Data Description Inc., 1996), and S-Plus version 7.0 (Insightful Corporation, 2005).

Habitat

Habitat data were checked for normal distributions and analyzed for multi-spatial scale relations with Spearman rank correlation (Iman and Conover, 1983; Data Description, Inc., 1996). For the habitat data, landscape and segment-scale characteristics were considered independent variables and most reach-scale habitat measurements were considered dependent variables. Some exceptions were reach-scale slope and reach-scale riparian-vegetation conditions. Reach-scale slope was considered an independent variable because most streams were not alluvial and instead flowed on glacial deposits, bedrock, or thin fluvial deposits in poorly developed valleys. In addition, slope is not sensitive to decadal changes in land cover.

Hydrology

Hydrologic data were analyzed for relations to biologic and landscape variables, using Spearman rank correlation analysis (Iman and Conover, 1983). Three sets of hydrologic data were compared for this study. The first set consisted of eight annual streamflow-summary statistics (table 3) based upon daily discharge values. Stage values at the

Table 3. Annual streamflow-summary statistics for eight U.S. Geological Survey streamflow-gaging stations and 22 pressure-transducer sites in the Milwaukee to Green Bay, Wis., study area.

[m^3/s, cubic meter per second; $(m^3/s)/km^2$, (cubic meter per second) per square kilometer. n = 30 for all characteristics. Characteristic definitions listed in appendix 1-5.]

Characteristic abbreviation	Median (m^3/s)	Minimum (m^3/s)	Maximum (m^3/s)	Definition
Q_bnkfl	1.35	0.23	5.66	Flow corresponding to bankful stage as determined during habitat survey; model derived
Qmax_inst	18.42	3.45	53.80	Maximum instanteous discharge
Q_max	11.38	2.41	35.96	Highest daily mean discharge
Q_ave	.56	.11	1.53	Annual mean discharge
Q_10	1.16	.26	3.45	Discharge exceeded 10 percent of the time
Q_50 × 1,000	100.5	21.2	453.1	Discharge exceeded 50 percent of the time
Q_90 × 1,000	19.5	2.0	226.5	Discharge exceeded 90 percent of the time
Q_7min × 1,000	6.9	.8	212.4	Lowest mean discharge for 7 consecutive days
Q_min × 1,000	3.4	.6	195.4	Lowest daily mean
Q_bnkflDA	29.3	5.2	126.2	Q_bnkfl, normalized by drainage area, $((m^3/s)/km^2)$ x 1,000
Qmax_instDA	393.2	84.4	2,641.0	Qmax_inst, normalized by drainage area, $((m^3/s)/km^2)$ x 1,000
Q_maxDA	237.1	83.5	967.3	Q_max, normalized by drainage area, $((m^3/s)/km^2)$ x 1,000
Q_aveDA	11.5	5.1	35.0	Q_ave, normalized by drainage area, $((m^3/s)/km^2)$ x 1,000
Q_10DA	27.9	12.4	60.8	Q_10, normalized by drainage area, $((m^3/s)/km^2)$ x 1,000
Q_50DA	2.7	.7	6.0	Q_50, normalized by drainage area, $((m^3/s)/km^2)$ x 1,000
Q_90DA	.50	.05	2.26	Q_90, normalized by drainage area, $((m^3/s)/km^2)$ x 1,000
Q_7minDA	.16	.02	2.12	Q_7min, normalized by drainage area, $((m^3/s)/km^2)$ x 1,000
Q_minDA	.11	.01	1.95	Q_min, normalized by drainage area, $((m^3/s)/km^2)$ x 1,000

22 pressure-transducer sites were converted to estimated discharge values, using a combination of collected discharge measurements and the USACE Hydrologic Engineering Centers-River Analysis System (HEC-RAS) (v. 3.0) 1-dimensional steady-flow hydraulic model (Brunner, 2001). The hydraulic model measured approximated channel geometry from the habitat survey, channel slope, and estimated channel roughness (Manning's n) to calculate flow depth and velocity; the model used conservation of mass and energy and boundary friction formulation for an open-channel, turbulent flow (Hoggan, 1996). At low flow, discharge was calculated based on measured stage-discharge relations. At medium to high flow, when in-stream discharge measurements were not taken, the stage-discharge relation was estimated, using the HEC-RAS model results. Daily-flow values for intervals of the stage record that were missing because of human error, pressure-transducer failure, or winter removal from the stream were estimated with the Missing Streamflow Estimation tool (MISTE). MISTE is a program available through the USGS National Water Information System (NWIS) that processes primary hydrologic data at a nearby index site, using a stepwise regression analysis to give an estimated daily-discharge value at the study site where values are missing (U.S. Geological Survey, 2005b). At the eight traditional discharge-monitoring sites, established stage-discharge ratings were used. These ratings, obtained over several years, were based on flow measurements and shifting-control method-correction factors (Kennedy, 1984). Additionally, bankfull flow as determined from habitat-observed bankfull height and the HEC-RAS model was included in this dataset.

The second hydrologic dataset consisted of the hydrologic-condition metrics (table 4) based upon an hourly record of a cross-sectional area in place of a wetted cross-sectional area at the transducer. A surveyed channel cross section at the location of the pressure transducer or the USGS streamflow-gaging station was combined with the continual stage record to calculate cross-sectional area at each stage value; this resulted in a continuous hourly record of cross-sectional area. From continuous cross-sectional data, 54 hydrologic condition metrics (HCM) were calculated to summarize hydrologic variability; the rate of change of flows (areas); and the magnitude, frequency, and duration of high- and low-flow (area) periods (table 4; appendix 1-5) (McMahon and others, 2003). Such measures of hydrologic variability have been shown to be related to the structure and function of aquatic assemblages (Poff and Ward, 1989; Poff and Allan, 1995; Richter and others, 1996).

Calculations were made for 20 measures of central tendency and flow (area) magnitude. Metrics for area magnitude were normalized by the median area to reduce the effect of differing drainage sizes. To characterize area (flow) flashiness, 22 metrics were calculated. The frequency of rise and fall rates of a specified magnitude was represented with eight metrics (table 4, appendix 1-5). These metrics are the number of change events (rising or falling cross-sectional-area) where the stream rise or fall is equal to or greater than 3, 5, 7, or 9 times the median stream-area rise or fall. For example, a value of 10 for periodr9 indicates there were 10 events during the period of record where the change in area value during the event was at least 9 times greater than the median change in cross-sectional area over all rising events. A flashy stream typically has more frequent high-change area events, and thus would have a higher value. Other flashiness metrics based on the hourly data included cumulative change, maximum- and median-change magnitudes, and maximum- and median-change durations. In addition, two flashiness metrics based on daily values were calculated; the Richards-Baker flashiness index (Baker and others, 2004), and an index of percent daily change (day_pctchange). The Richards-Baker flashiness index measures oscillations in daily flow (area) relative to total flow (area) over a period of record.

$$\frac{\sum | \mathit{flow}(t) - \mathit{flow}(t-1) |}{\sum \mathit{flow}(t)}, \tag{3}$$

where

Σ is the summation; and

t is the time.

Index values were calculated for 59 sites with drainage areas of less than 78 km^2. The flashiness index ranged from about 0.1 to 1.4; most sites were between 0.45 and 0.75 (Baker and others, 2004). A low index value typically indicates a stable or less-flashy stream; a high value indicates an unstable or flashy stream.

Daily percent change represents the sum of all daily change in mean flow, summed over the period of record.

$$\sum \frac{| \mathit{flow}(t) - \mathit{flow}(t-1) |}{\mathit{flow}(t)} \tag{4}$$

A low value indicates small incremental changes in daily mean flow (area); a high value indicates large changes in daily mean flow (area). Duration of flow (area) was represented by two subgroups of six hydrologic-condition metrics (appendix1-5). High flow (area) discharge was defined as an area value exceeding the 75, 90, and 95 percent of all area values, and low discharge was defined as an area value less than the 25, 10, and 5 percent of all area values.

The third hydrologic dataset consisted of the same hydrologic-condition metrics (table 4) based upon the hourly discharge record. To obtain a reduced set of HCM, data were examined for correlations between the 108 pre- and post-ice HCM metrics and 9 annual streamflow statistics (tables 3 and 4) with biological metrics (53 fish, 133 invertebrate RTH, and 112 algae metrics). An HCM was retained if it had a rho value significant at a level of p = 0.001 with at least one biological metric. The HCM also was retained if it had rho values significant at a level of p = 0.01 with at least five biological metrics. An HCM was removed if it strongly correlated with another HCM in its same grouping (pre-ice, post-ice, or annual streamflow statistic).

Water Chemistry

A combination of non-parametric Spearman rank correlations and x-y scatterplots were used to examine relations between water chemistry and landscape variables. When the rho value was 0.58 or greater and a distinct pattern was observed in the scatterplots, the individual correlations were examined as part of the data analysis and interpretation.

Water-chemistry data were assessed for seasonal variation using the Kruskal-Wallis test (Kruskal and Wallis, 1952) and scatterplots. The Kruskal-Wallis test was used to test differences in the high-intensity sampling data when concentrations were grouped by seasons and concentrations were considered significantly different for p-values equal to or less than 0.05. Variables with a p-value ≤0.05 were plotted to determine if a seasonal response was observed in the plots. These data then were plotted against the UII to determine if the seasonal response differed across the urban gradient.

Table 4. Selected area-based hydrologic-condition metrics for the pre-ice (Oct. 1–Dec. 8, 2003) and post-ice periods (Mar. 16–Oct. 30, 2004) used to determine effects of urbanization on hydrology for 30 sites in the Milwaukee to Green Bay, Wis., study area.

[Metric definitions and units are listed in appendix 1-5; metric suffixes “pre” and “pst” refer to pre-ice and post-ice periods, respectively.]

Metric abbreviation (pre-ice)	Number of sites	Median	Minimum	Maximum	Metric abbreviation (post-ice)	Number of sites	Median	Minimum	Maximum
cv_pre	22	27.86	15.31	90.58	cv_pst	24	54.70	32.02	377.95
skew_pre	22	3.59	1.19	9.34	skew_pst	24	4.59	1.80	9.34
cv_log_pre	22	12.33	6.62	33.91	cv_log_pst	24	20.03	11.46	124.62
coef_disp_pre	22	.18	.06	.50	coef_disp_pst	24	.40	.17	4.00
mean_pre	22	3.06	.87	6.57	mean_pst	24	3.03	.63	7.12
median_pre	22	2.95	.80	6.10	median_pst	24	2.70	.20	6.10
pct_99n_pre	22	2.54	1.54	8.69	pct_99n_pst	24	4.36	2.39	49.88
pct_95n_pre	22	1.57	1.23	3.13	pct_95n_pst	24	2.35	1.56	10.00
pct_90n_pre	22	1.28	1.10	2.30	pct_90n_pst	24	1.71	1.33	7.00
pct_75n_pre	22	1.09	1.05	1.30	pct_75n_pst	24	1.27	1.11	4.00
pct_25n_pre	22	.92	.75	1.00	pct_25n_pst	24	.85	.00	.95
pct_10n_pre	22	.85	.63	.97	pct_10n_pst	24	.75	.00	.90
pct_5n_pre	22	.85	.63	.97	pct_5n_pst	24	.75	.00	.89
pct_99a_pre	22	7.30	1.90	33.10	pct_99a_pst	24	12.80	4.30	39.90
pct_95a_pre	22	4.30	1.50	10.40	pct_95a_pst	24	6.50	2.00	18.70
pct_90a_pre	22	3.35	1.30	8.40	pct_90a_pst	24	4.75	1.40	11.30
pct_75a_pre	22	3.15	1.00	6.50	pct_75a_pst	24	3.30	.80	7.50
pct_25a_pre	22	2.60	.60	5.80	pct_25a_pst	24	2.35	.00	5.50
pct_10a_pre	22	2.45	.50	5.60	pct_10a_pst	24	2.00	.00	5.10
pct_5a_pre	22	2.45	.50	5.50	pct_5a_pst	24	1.95	.00	5.00
day_pctchange_pre	22	4.19	2.11	9.72	day_pctchange_pst	24	21.61	9.20	334.33
rb_flash_pre	22	.09	.04	.22	rb_flash_pst	24	.13	.06	.51
cumm_change_pre	22	67.30	29.80	222.80	cumm_change_pst	24	319.75	137.20	1,260.10
cumm_median_pre	22	26.25	11.89	109.88	cumm_median_pst	24	134.76	45.34	3,636.00
max_torise_pre	22	3.80	.60	29.00	max_torise_pst	24	13.65	3.30	93.40

Table 4. Selected area-based hydrologic-condition metrics for the pre-ice (Oct. 1–Dec. 8, 2003) and post-ice periods (Mar. 16–Oct. 30, 2004) used to determine effects of urbanization on hydrology for 30 sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[Metric definitions and units are listed in appendix 1-5.]

Metric abbreviation (pre-ice)	Number of sites	Median	Minimum	Maximum	Metric abbreviation (post-ice)	Number of sites	Median	Minimum	Maximum
med_torise_pre	22	0.10	0.10	0.20	med_torise_pst	24	0.10	0.10	0.20
max_tofall_pre	22	2.10	.50	23.10	max_tofall_pst	24	11.45	1.40	76.90
med_tofall_pre	22	.10	.10	.20	med_tofall_pst	24	.10	.10	.20
periodr1_pre	22	118.5	44	205	periodr1_pst	24	326.0	84	544
periodr3_pre	22	8.5	3	25	periodr3_pst	24	41.5	14	105
periodr5_pre	22	6.0	2	22	periodr5_pst	24	29.5	9	92
periodr7_pre	22	4.5	0	22	periodr7_pst	24	23.0	9	81
periodr9_pre	22	3.5	0	20	periodr9_pst	24	19.5	7	71
periodf1_pre	22	144.5	68	240	periodf1_pst	24	433.5	297	708
periodf3_pre	22	6.5	1	25	periodf3_pst	24	42.0	6	116
periodf5_pre	22	3.0	0	21	periodf5_pst	24	23.5	3	93
periodf7_pre	22	3.0	0	20	periodf7_pst	24	17.5	2	84
periodf9_pre	22	2.0	0	18	periodf9_pst	24	15.5	2	77
max_durise_pre	22	7.00	3	20	max_durise_pst	24	11.00	4	28
med_durise_pre	22	1.00	1	1	med_durise_pst	24	1.00	1	1
max_durfall_pre	22	10.00	2	33	max_durfall_pst	24	22.50	5	69
med_durfall_pre	22	1.00	1	1	med_durfall_pst	24	1.00	1	1
MXH_75_pre	22	171.50	58	360	MXH_75_pst	24	435.00	136	825
MXH_90_pre	22	96.00	39	148	MXH_90_pst	24	133.50	58	233
MXH_95_pre	22	58.00	23	81	MXH_95_pst	24	81.00	38	147
MDH_75_pre	22	3.75	1	72	MDH_75_pst	24	6.25	2	216
MDH_90_pre	22	10.75	2	45	MDH_90_pst	24	21.00	4	91
MDH_95_pre	22	24.75	1	81	MDH_95_pst	24	14.25	3	50
MXL_25_pre	22	116.00	16	408	MXL_25_pst	24	348.00	0	976
MXL_10_pre	22	20.50	0	114	MXL_10_pst	24	62.50	0	526
MXL_5_pre	22	7.50	0	114	MXL_5_pst	24	25.00	0	115
MDL_25_pre	22	2.50	1	53	MDL_25_pst	24	2.75	0	52
MDL_10_pre	22	2.00	0	59	MDL_10_pst	24	2.00	0	271
MDL_5_pre	22	1.00	0	59	MDL_5_pst	24	2.00	0	54

Water-chemistry samples were collected as close to the same time as possible and under similar hydrologic conditions to compare data among sites. This was not always possible because of a number of factors including time constraints of the study, a north-to-south gradient of temperature and rainfall during the study, and localized meteorological impact from the Great Lakes. Above-average rain fell over a large part of the study area from April through June; below-average rainfall fell over the entire study area in July and August. Because of these and other factors affecting hydrology, not all samples were collected during base flow (base flow is defined as at or above discharge exceeded 90 percent of the time [Q90]). During the May and June 2004 sampling, measured discharges were generally between Q10 and Q50 (discharge exceeded 10 and 50 percent of the time); discharges at two sites were between Q50 and Q80 (discharge exceeded 50 and 80 percent of the time). During the late-summer ecological sampling (August and September 2004) the majority of sites were at base-flow conditions; at only one site was the discharge slightly greater than Q90. With the small number of samples and short time for this study, adjusting concentration for flow could have introduced additional error in the correlations. For the purpose of this study, correlations were reviewed independently for spring and summer samples at 30 sites; overlapping correlations also were reviewed. Correlations were calculated for individual pesticide and SPMD chemistry that were detected in at least 33 percent of the samples.

In addition to reviewing individual pesticide chemicals and summing concentrations of classes of pesticides (herbicides, insecticides, and fungicides) a pesticide toxicity index (PTI) (Munn and Gilliom, 2001) was calculated for each sample. The PTI is calculated by combining pesticide exposure of aquatic biota with toxicity estimates of specific pesticides to produce a single index value for a sample or site. The PTI was supplemented with updated toxicity data (Lisa H. Nowell and Patrick W. Moran, U.S. Geological Survey, written commun., May 13, 2005). PTI values were calculated for three taxonomic groups: fish, benthic invertebrates, and cladocerans for each individual sample. The PTI is not a direct measure of toxicity to biological communities; rather it is a way to aggregate pesticide concentrations in a biologically relevant manner. The PTI does not take into consideration environmental factors that can affect the bioavailability of pesticides; it assumes there is no chemical interaction among pesticides. The median number of bioassays in the three taxonomic groups is small and could cause uncertainty in the toxicity of compounds. Even with these limitations, the PTI can be used to compare the potential significance of pesticides in different streams and compare the potential toxicity of sites when studying relations between multiple pesticide detections and aquatic ecosystems (Munn and Gilliom, 2001).

Quality-assurance/quality-control (QA/QC) samples included field blanks and sample splitter replicates. Results of field blanks showed the concentrations of all constituents were below the detection limit in blanks, with the exception of dissolved organic carbon. Dissolved organic carbon was detected in every blank but at concentrations below corresponding environmental concentrations. Concentrations for sample splitter replicates were similar to environmental samples. Cholesterol, 2-methylnapthalene, diethyl phthalate, and diethylhexyl phthalate were detected in the SPMD trip blanks. These compounds were detected in less than 10 of the environmental samples and were not included in the data analysis. For the purpose of data analysis, all dialysis and solvent blank data for SPMDs manufactured at the same time were pooled and field values were censored at the maximum blank and/or reporting limit; blank values were subtracted from field values (Sprague and others, 2006).

Biology

Biological-assemblage data (species relative abundance in percent) and metrics computed from assemblage data were used in analyses. Biological metrics computed included descriptive statistics such as richness measures, composition (relative-abundance) measures, tolerance indices, diversity indices, and functional feeding-group composition.

The RTH algal assemblage at the 30 sites consisted of 198 separate algal taxa; the DTH algal assemblage contained 256 algal taxa. Algal abundance data were normalized to the relative abundance of each species, based on total abundance at each site. Algal metrics (appendix 1-8), including tolerance indices, were calculated using non-transformed relative-abundance values for taxa that were classified for each metric (Van Dam and others, 1994; Porter, 2008). These metrics were used to calculate correlations with the environmental characteristics of GIS, habitat, hydrology, and water chemistry.

Relations to environmental characteristics were examined with 164 invertebrate taxa in RTH samples and a reduced dataset of 83 RTH taxa that excluded rare occurrences (taxa with occurrences at only one to two sites with less than 5 percent total densities); limited analyses were done with metrics computed from a combined RTH and QMH taxa list (QQ). Descriptive statistics including richness measures, composition (relative-abundance) measures, tolerance indices, diversity indices, and functional feeding-group composition were calculated (appendix 1-9). Invertebrate metrics were based on either raw abundances or relative densities of invertebrate taxa at each site after ambiguities had been resolved. The USGS Invertebrate Data Analysis System (IDAS) version 3.6 was used to resolve taxonomic ambiguities and calculate 141 metrics (Cuffney, 2003). Taxonomic ambiguity occurs when a taxon (a unique group of organisms) is reported at one or more lower or higher taxonomic levels within the taxonomic hierarchy (Cuffney, 2003). Functional feeding-group and regional-tolerance metrics were derived from appendix B of the USEPA’s Rapid Bioassessment Protocol (RBP) included in the IDAS program (Barbour and others, 1999).

A total of 56 fish taxa were identified and used in data analyses. Fish metrics were based on species traits such as substrate preference, geomorphic preference, trophic ecology or feeding preference, locomotion, reproductive strategy, and stream-size preference; these were included with selected metrics commonly included in fish Indexes of Biotic Integrity (IBI) in the Midwest, such as number of individuals and taxa (richness) and abundance of certain families and functional groups (appendix 1-10; Karr and others, 1986; Lyons, 1992; Barbour and others, 1999; Goldstein and Meador, 2004). Warmwater IBI scores were calculated according to Lyons (1992) for all sites except Jambo Creek, for which a coldwater IBI score was calculated (Lyons and others, 1996). Ratings and scores for the fish IBI are "excellent" (100–65), "good" (64–50), "fair" (49–30), "poor" (29–20), and "very poor" (19–0).

As mentioned earlier, several methods including Spearman rank correlation, x-y scatterplots, and multivariate analyses were used to initially examine relations between biological assemblages and environmental characteristics and to reduce the number of collinear (rho > 0.80) characteristics for input in subsequent multivariate analyses. For ecological data, the multivariate ordination techniques, Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA) in CANOCO program version 4.5, use species relative-abundance data to assess non-linear or unimodal relations (Gauch, 1982; ter Braak and Smilauer, 2002). Although DCA and CCA are robust to non-normality, species relative-abundance data (percentages) were arcsin-squareroot transformed prior to input, and environmental data were transformed as necessary to satisfy requirements of normality for input into CCA. DCA was used to initially examine relations between sites based on species relative abundance; however, DCA can be affected by skewed species distributions. DCA results also were used to indirectly examine relations between biological assemblages and environmental characteristics. The first four DCA axes scores were used as additional metrics in correlations (Kilgour and others, 2004) to guide selection of the subset of environmental characteristics used in CCA. CCA was used to directly examine relations between the species relative-abundance data and a subset of the environmental characteristics; selections were based on the outcomes of Spearman rank correlations between DCA axes scores or other metrics and environmental characteristics. In CCA ordination plots, environmental characteristics are represented by arrows. Arrows extending in the same direction indicate a positive relation, and arrows extending in opposite directions indicate a negative relation. Lengths of arrows represent importance of an environmental characteristic to a biological assemblage; small angles between arrows represent correlations between selected environmental characteristics. The proximity of sites and species relative to each arrow (and an imaginary line extended in the opposite direction of the arrow) represents the strength of the site or species relation to that environmental characteristic (Palmer, 1993). Percentage of total impervious surface was used in multivariate analyses as a representative characteristic for chloride, urban land metrics, and road indices because of the high correlations (rho > 0.8) among these characteristics. Richards-Baker flashiness index (rb_flash), available for all 30 sites, was used in multivariate analyses as a representative variable for several other hydrologic variables that would have limited such analyses to 22 or 24 sites because of incomplete records for these other hydrologic characteristics. The Richards-Baker flashiness index is a computation of the average percent change in flow and is not a cumulative or count metric as most other hydrologic-condition metrics that were computed; thus it was not as sensitive to partial record issues. The index is considered to be relatively stationary through time (Baker and others, 2004).

Results and Discussion

Landscape, Physical, Chemical, and Biological Characteristics and Relations Between Characteristics

Relations Between Landscape Characteristics

For the Milwaukee to Green Bay study, the urban intensity index, 2000 population density (POPDENKM), percentage of impervious surface in the watershed (NLCD_IS), percentage of developed land in the watershed (P_NLCD1_2), and household density (HHDEN) were all positively correlated (rho ≥0.95). These results are similar to other urban studies (McMahon and Cuffney, 2000). The urban intensity index also correlated with road density (rho = 0.94) and percentage of developed land (rho = 0.93) and impervious surface (rho = 0.92) in the 100-m riparian zone. The percentage of impervious surface in the watershed (NLCD_IS) was highly correlated (rho = 0.96) to that in the riparian zone (NLCD_BIS); this close association makes it difficult to separate effects of impervious surface in the watershed compared to the riparian zone.

The study design attempted to keep physiographic variations to a minimum; however, land-cover patterns develop in relation to geologic setting because natural features tend to promote or inhibit certain types of land development (for example, flat terrain with productive soils will be developed before steep terrain or sandy soils). Based on national STATSGO statistics, sites with the highest percentages of watershed urban land also contained clayey surficial deposits with low permeability, less relief, and high water table; this reflects the proximity of the large urban centers (Milwaukee and Green Bay) to the flat-terrain glacio-lacustrine clay plain near Lake Michigan (U.S. Department of Agriculture, 1994). Based on Wisconsin glacial geology maps, 28 out of the 30 sites showed greater than 70 percent watershed clayey surficial deposits (Richmond and Fullerton, 1983; 1984); two outliers were the Fox River, with 9 percent, and the Menomonee River, with 24 percent. These two sites are in less-developed areas (5 and 10 percent impervious surface, respectively). Thus there is notable discrepancy between the national and state-based maps that were used to characterize the surficial deposits (Richmond and Fullerton, 1983; 1984; U.S. Department of Agriculture, 1994).

The amount of natural vegetation (forest and wetland land cover) in the 100-m riparian zone correlated with watershed surficial deposits (P_TEXTURE3, medium to coarse and P_HSG_2, soil hydrologic group B with a 4 to 8 mm per hour infiltration rate) and watershed slope (rho = 0.79–0.81 and 0.58 respectively). More natural vegetation (forest and wetland land cover) in the 100-m riparian zone was found along streams with sandy surficial deposits and relatively steep slope.

The amount of shrubland in the watershed correlated with watershed urban land ($r = 0.71$). In the Midwest, agricultural land around the fringes of development typically is abandoned for several years to a decade before the land is developed—a sufficient time for shrubs to establish prior to development. In the Muskegon River Watershed, Mich., the transition from agriculture to urban was not immediate but happened through a four-step process as a result of a variety of complex socioeconomic factors: from agriculture, to shrubland, to forest, to urban (Bryan Pijanowksi, Purdue University, written commun., 2003).

Climatic Conditions

During the study, the mean annual air temperature in the study area was similar (within 0.1° to 0.3°C) to the long-term mean (1971–2000) as measured at the four airport weather stations (Green Bay, Milwaukee, Racine, and Kenosha). Spatially, however, a long-term north-south mean annual air-temperature gradient of 1.5°C exists across the study area (fig. 11) (Falcone and others, 2007; University of Montana Numerical Terradynamic Simulation Group, 2005). During the study, the north-south air-temperature gradient was greatest between November and March with the maximum difference of 3.4°C in January 2004 (fig. 12).

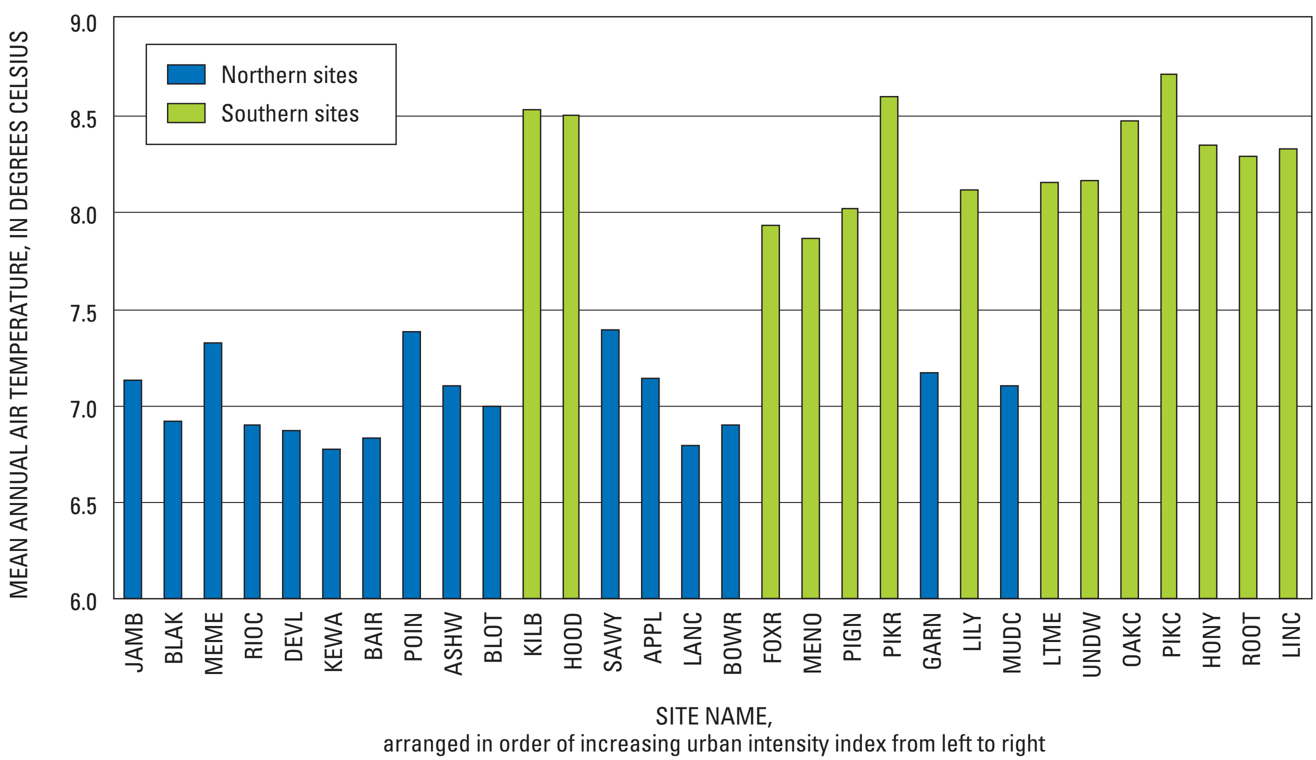


Figure 11. Mean annual air temperature (18-year mean) for 30 study sites in the Milwaukee to Green Bay, Wis., study area (University of Montana Numerical Terradynamic Simulation Group, 2005).

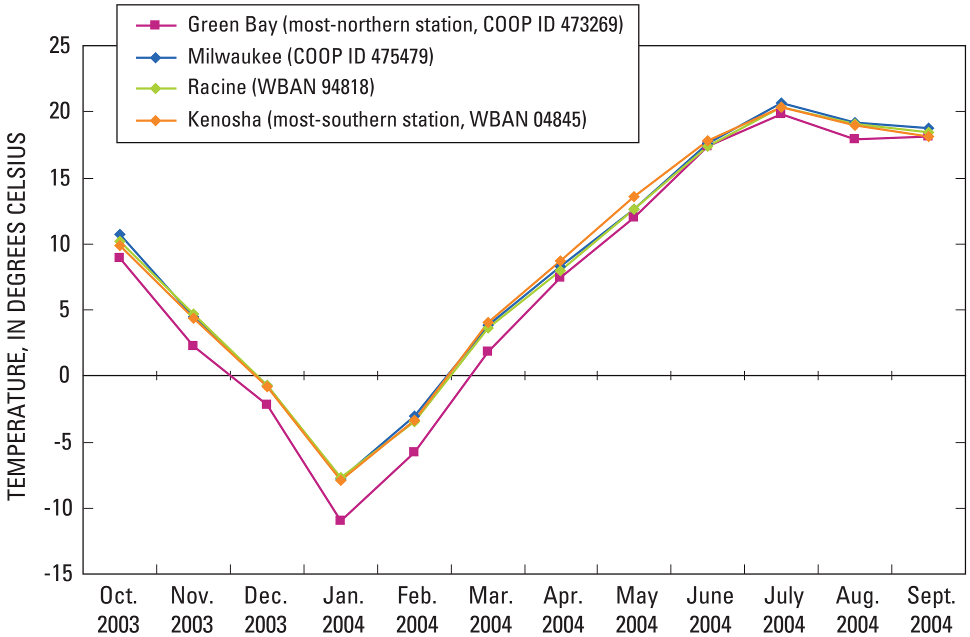


Figure 12. Monthly air temperatures at four National Oceanic and Atmospheric Administration (NOAA) stations in the study area encompassing the north-south gradient in the Milwaukee to Green Bay, Wis., area (National Climatic Data Center, 2007).

The spatial climatic effect on stream temperature (figs. 13*A*, *B*) was removed by subtracting monthly long-term mean air temperature at each site from stream temperature, with the resultant temperature denoted as $T_{s\text{-}a}$. All subsequent temperature analyses were conducted using the spatially normalized $T_{s\text{-}a}$ variable. During November 2003, and March and June 2004 there was up to a ~2.5°C change across the urban gradient (fig. 13*C*).

For the majority of the study period, there was either no relation with monthly stream temperature ($T_{s\text{-}a}$) and urbanization, or stream temperature increased slightly with urbanization (fig. 13*C*). Increasing stream temperature correlated with increased urbanization during November (rho~0.63) and March (rho~0.59). An unanticipated association occurred in June when stream temperature decreased with increasing urbanization. In late May, a period of heavy rainfall produced a peak discharge on ~May 22 (fig. 14). Based on analyses of weekly data, some of the strongest decreasing stream-temperature ($T_{s\text{-}a}$) relations with urbanization occurred after this peak-discharge period, specifically June 1 through 8 and June 17 through 24 (fig. 14). During each of these periods, there was about a 3.5°C decrease in stream temperature across the urban gradient.

There may be two reasons for the above transient negative relation between urbanization and stream temperature. During warm summer precipitation, a portion of infiltration leads to interflow (water that infiltrates into soil and flows laterally in the surface soil to stream channel) (Linsley and Franzini, 1979). The less-urbanized sites have greater infiltration and therefore an extended interflow of this warmer water (as compared to cooler groundwater) than the more urbanized sites do. Additionally, the less-urbanized sites do not have engineered conveyance systems such as storm sewers and concrete channels that decrease surface-water travel time. Therefore the more-urbanized sites will return to the cooler groundwater inflow as the major component of streamflow sooner than less-urbanized sites. Both may occur in brief periods of time, following heavy precipitation, during which lower stream temperatures are observed at the more-urbanized sites.

A clear distinction was evident between the three hydrographs (normalized for watershed area) during the time interval, with the strongest negative association between urbanization and stream temperature (fig. 15*A*, *C*, *E*). The least-urbanized site (fig. 15) (Hoods Creek) showed higher flow per area than the more-urbanized sites (Lincoln Creek and Oak Creek)—supporting the concept of increased surface or interflow (warmer temperature) flux in the less-urbanized sites during these transient periods. From June 17 to June 24, there was nearly 10 times more streamflow per drainage area in the less-urbanized site (Hoods Creek) than in more-urbanized sites (fig. 14). This is a possible indication that the warmer temperature transient overland flow and interflow may be a major component of streamflow (fig. 15*E*).

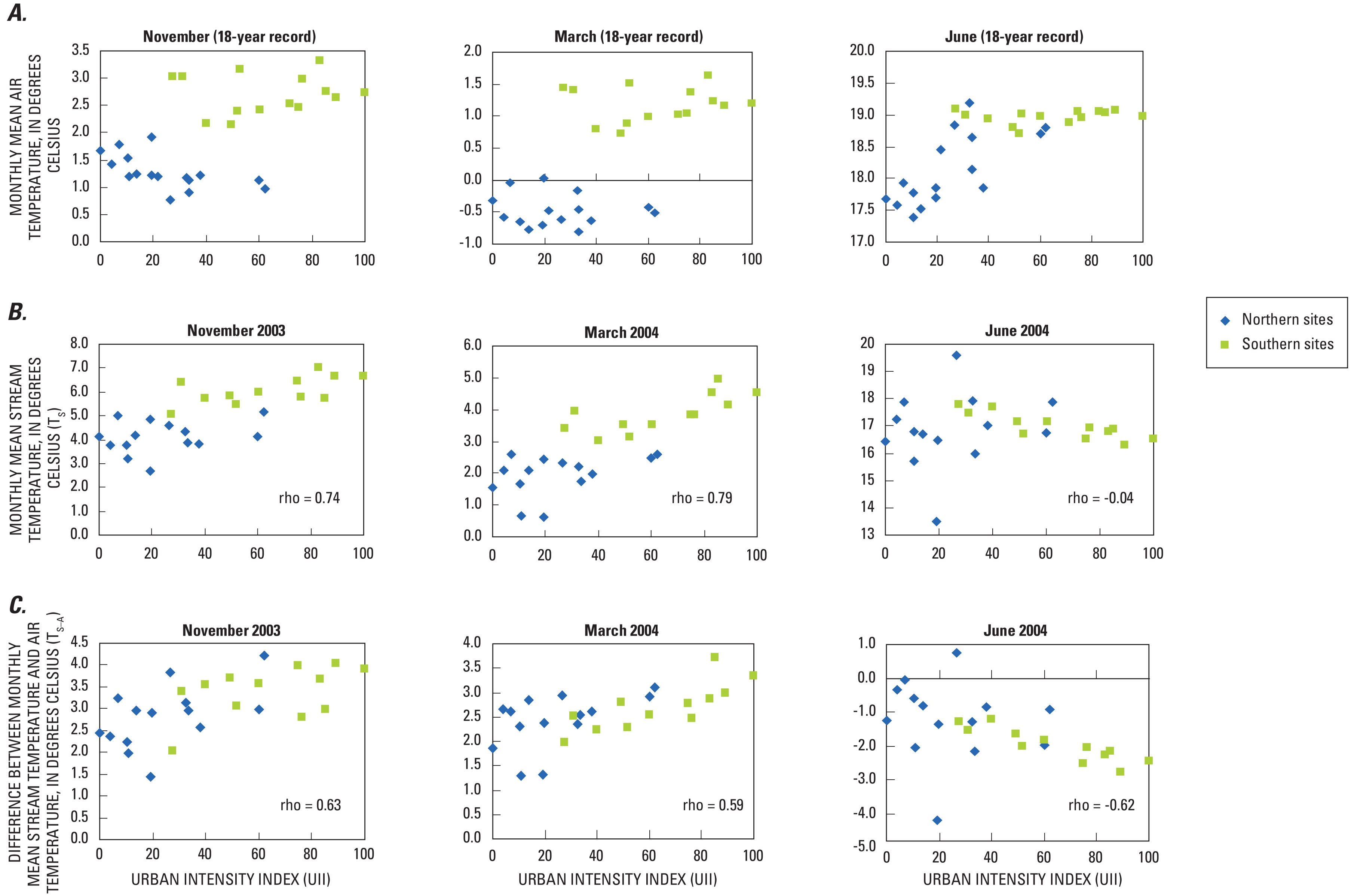


Figure 13. *A*, Historical monthly mean air temperature (University of Montana Numerical Terradynamic Simulation Group, 2005) and showing relations between urban intensity index and *B*, monthly mean stream temperature, and *C*, difference between stream temperature and air temperature for 26 study sites in March, June, and November, 2004, in the Milwaukee to Green Bay, Wis., study area.

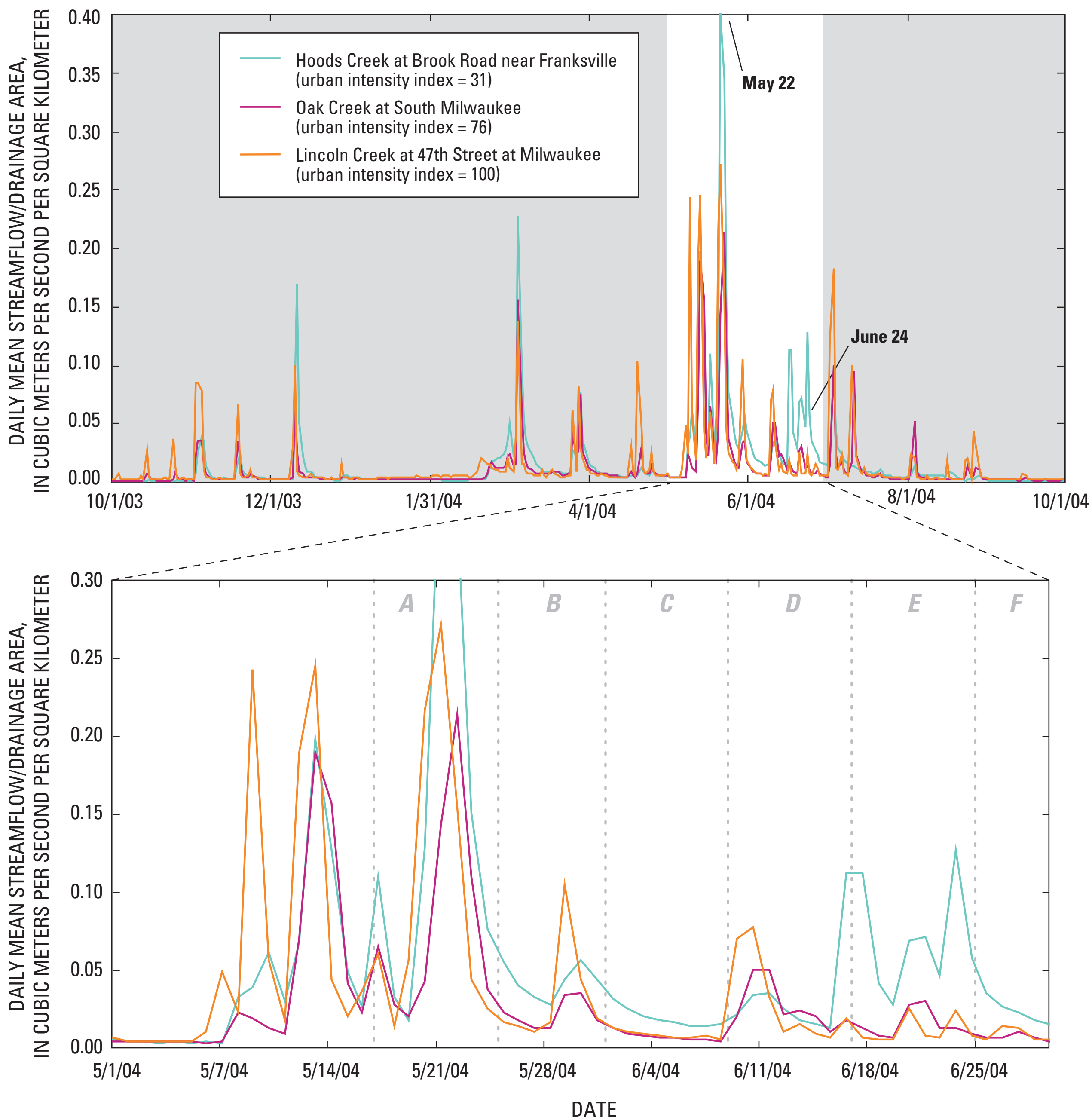


Figure 14. Discharge per watershed area for water year 2004 and a summer storm period at three southern study sites in the Milwaukee to Green Bay, Wis., study area.

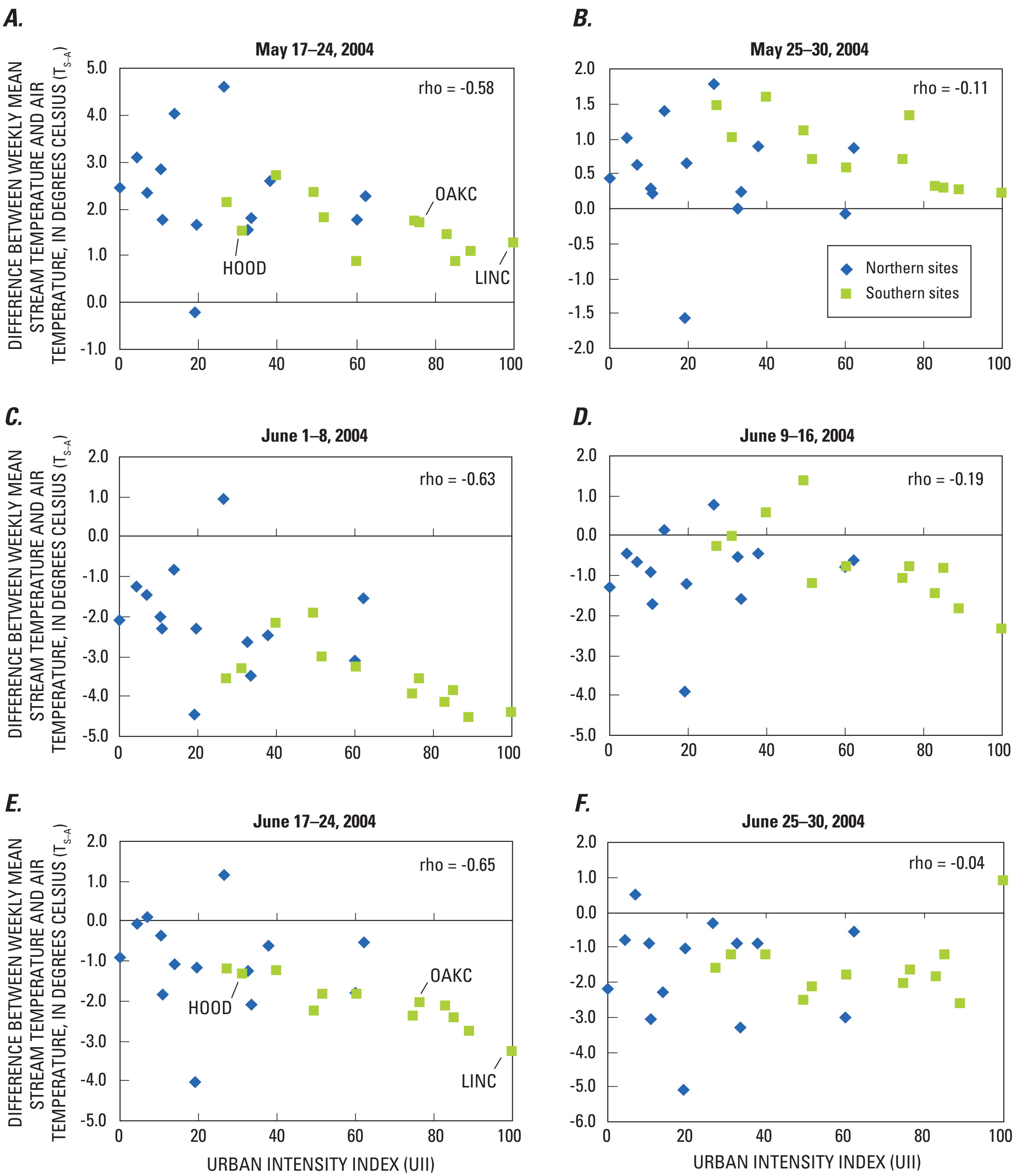


Figure 15. Relations between weekly mean stream temperature and air temperature and urban intensity index for 26 study sites during six 1-week intervals, May 25 to July 8, 2004, in the Milwaukee to Green Bay, Wis., study area.

Total precipitation during the study period ranged from 81 to 92 cm. Annual precipitation in water year 2004 in the northern area was 10 percent greater than the long term mean (1971–2000) of 74 cm; the southern area was 1, 2.5, and 3 percent wetter than the long-term mean at the progressively southern Milwaukee (88.4 cm), Racine (89.8 cm), and Kenosha (88.2 cm) weather stations. March, May, and June 2004 were wet, with May rainfall 2.5 to 3.5 times greater than the long-term average (fig. 16*A*). Kenosha reported a record rainfall of 29.3 cm during the month of May (National Climatic Data Center, 2007) (fig. 16*B*). Lower-than-average rainfall was recorded, July through August, the months preceding the ecological survey.

In the first 24 days of May, rainfall totals throughout the southern area ranged from about 14 to 28 cm. Within this period, there was an intense 3-day period of rainfall with a probability of recurrence in the Kenosha/Racine area of 1 in 20 to 1 in 50 years (Southeast Wisconsin Regional Planning Commission, 2004). This rainfall produced a record peak discharge for the Pike River streamflow-gaging station (04087257) near Racine—a flow with an estimated recurrence interval of 1 in 50 to 100 years. The recurrence interval for the peak discharge at the Menomonee River was 10 to 25 years. Water year 2004 was a year of high peak discharges and sustained high flows. Sustained high flows (Q10) for the five USGS streamflow-gaging stations proximate to or within the study area were higher during the study period than during the entire period of record. (table 5).

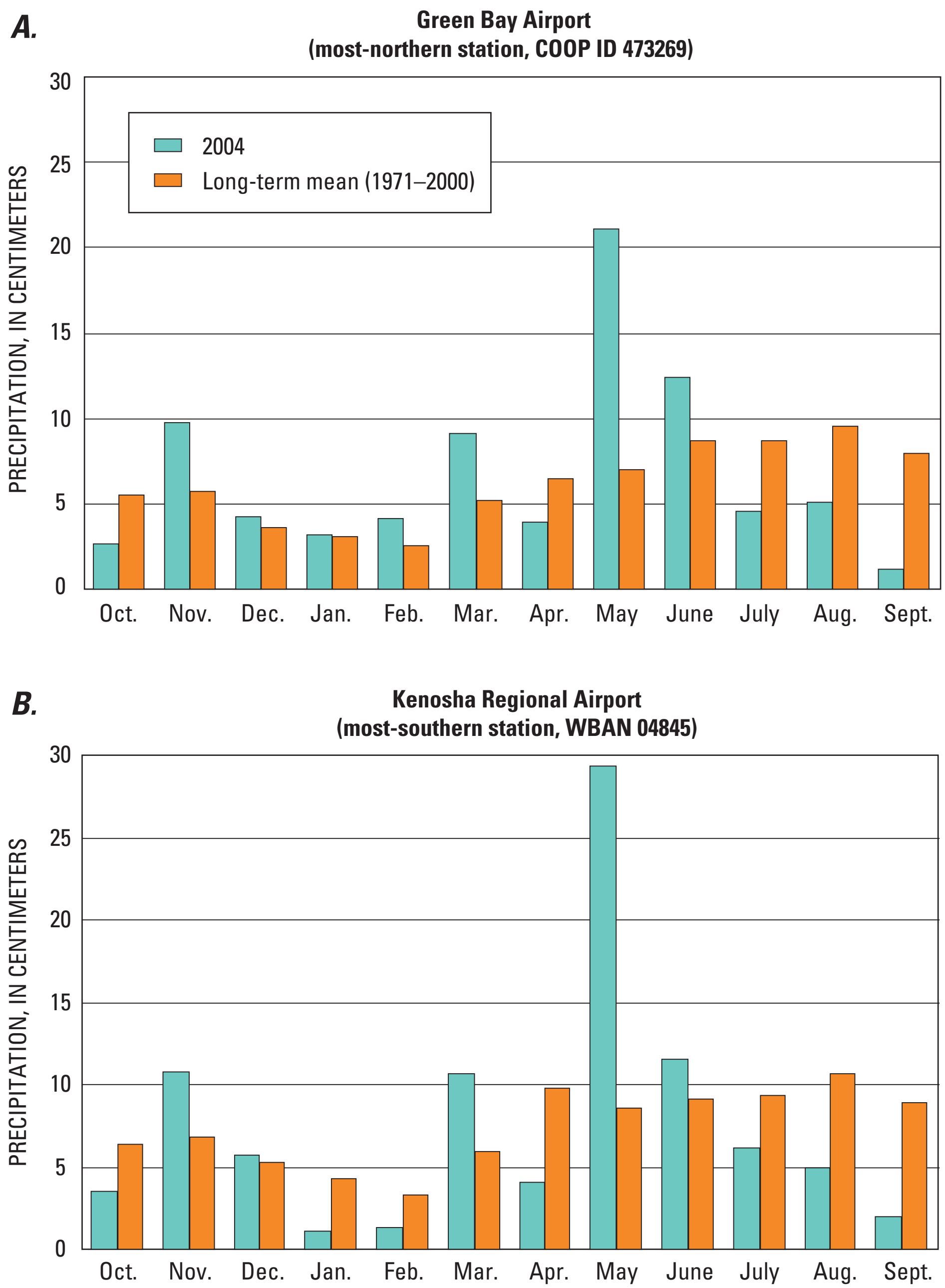


Figure 16. Long-term (1971–2000) mean precipitation and water year 2004 monthly precipitation at the *A*, most-northern and *B*, most-southern weather stations in the Milwaukee to Green Bay, Wis., study area (National Climatic Data Center, 2007).

Conversely, at low flow (Q90), a less-consistent pattern was apparent between sites when comparing water year 2004 to long-term low-flow records. At four of the five sites, the 2004 low flow was 16 to 33 percent greater than the long-term record. The Menomonee River at Menomonee Falls site, however, recorded decreased low flow in 2004 (-24 percent) (table 5).

Table 5. Selected annual streamflow characteristics for water year 2004 and period of record for five long-term U.S. Geological Survey (USGS) streamflow-gaging stations in the Milwaukee to Green Bay, Wis., study area.

[USGS, U.S Geological Survey; km^2, square kilometer; m^3/s, cubic meter per second; Qmax_inst, maximum instaneous discharge; Q10, discharge exceeded 10 percent of the time; Q50, discharge exceeded 50 percent of the time; Q90, discharge exceeded 90 percent of the time. Characteristic definitions listed in appendix 1-5.]

Site name	USGS station number	Drainage area (km^2)	October 2003–September 2004				Long-term period of record				
			Qmax_inst (m^3/s)	Q10 (m^3/s)	Q50 (m^3/s)	Q90 (m^3/s)	Period of record	Qmax_inst (m^3/s)	Q10 (m^3/s)	Q50 (m^3/s)	Q90 (m^3)
Duck Creek near Howard, Wis.	04072150	279.7	39.6	9.2	0.54	0.02	1988–2004	128.0	3.5	0.20	0.01
Kewaunee River near Kewaunee, Wis.	04085200	328.9	70.5	7.5	1.1	.45	1963–2004	242.7	4.7	.8	.34
Menomonee River at Menomonee Falls, Wis.	04087030	87.9	30.9	3.2	.42	.09	1975–2004	42.5	1.9	.40	.12
Oak Creek at South Milwaukee, Wis.	04087204	66.8	20.7	1.5	.22	.06	1964–2004	32.3	1.4	.22	.05
Pike River at County Hwy A near Racine, Wis.	04087257	100.3	46.7	3.5	.45	.23	1972–2004	46.7	2.3	.45	.17

Habitat

Habitat characteristics in the 30 sites were representative of agricultural and urban areas in eastern Wisconsin (table 2). Stream slopes were gentle, with mostly run habitat. Depth, velocity, and discharges during the time of sampling were low, reflective of the small drainage areas. Stream-bed substrates ranged from silt to large cobbles. High percentages of silt covered the streambed substrate of many of the study sites. Streambed-substrate-stability values (d_{50}/critical d_{50}) for 14 of the sites were less than 1.0; this suggests that about half of the sites' substrates were large enough to remain immobile during bankfull flows. Banks were generally silty, with low percentages of bank vegetation. Most banks (91 percent) were recorded as having the presence of some erosion. Disturbed riparian vegetation was found along the banks of most of the sites, with closed canopy angles that reflect the preponderance of tree-lined banks. River engineering modifications were evident for 18 sites and included 14 channelized sites and 13 sites with bank stabilization or grade control (10 of the 13 were channelized).

Spearman rank correlation analysis of habitat characteristics with landscape characteristics indicated that bankfull-channel size and bank erosion increased with increasing urbanization (table 6; figs. 17*A* and 17*E*). Unit-area bankfull-channel area (BFAreaNoPoolsDA) correlated similarly (rho = 0.57–0.59) with urban indicators such as the UII, watershed and 100-m riparian zone impervious surface, watershed developed land, distance to nearest urban land, road density, and percentage of patch adjacencies that are developed land. These relations were similar for bankfull characteristics that included or excluded pools; however, correlation coefficients were higher for calculations that excluded pools (bankfull characteristics excluding pools are shown in tables 6 and 7). Increases in bankfull-channel dimensions with increasing urbanization have been documented in other U.S. studies (Hammer, 1972; Gregory and others, 1992; Paul and Meyer, 2001; Center for Watershed Protection, 2003; Fitzpatrick and others, 2005; Konrad and others, 2005). As urbanization increases in previously undeveloped areas, bankfull-channel area increases, reflecting increases in flood frequency and duration related to increased impervious surface (Graf, 1975).

Urban sites with a relatively high percentage of watershed forested land and wetland had smaller than expected bankfull-channel areas. Bankfull-channel areas for Oak Creek, Underwood Creek, and Root River were smaller than expected (fig. 17*A*). These study watersheds are within the forest preserve network of Milwaukee. The Green Bay/Fox River Valley communities do not have an equivalent forest preserve network.

Habitat characteristics that reflect reach water volume (such as wetted volume, area, width, and depth) are dependent on stream size and drainage area and not on urbanization (fig. 17*B*). Wide channels (high WidthDepthAvg) had more riffles, more reach-scale riparian disturbance (RipLU), less fines, less embedded streambed substrate, and less bank erosion than deep channels (table 7).

Table 6. Spearman rank correlations between the reduced habitat and geographic information system (GIS) variables for 30 sites in the Milwaukee to Green Bay, Wis., study area.

[<, less than. For individual correlations, n = 30, for p ≤ 0.001, rho = 0.580 (dark green); for p ≤ 0.01, rho = 0.467 (green); for p ≤ 0.05, 0.362 (light green); with Bonferroni adjustments for multiple tests (53), the critical rho is 0.66 for a p-value of 0.05. Correlations greater than the Bonferroni adjustment are in **bold**. Characteristic definitions are listed in appendixes 1-2 and 1-4.]

Habitat characteristic abbreviations	GIS characteristic abbreviations									
	UII	NLCD_IS	P_NLCD1_2	P_NLCD_21/ P_NLCD1_2	POP90_00	ROADDEN	pURBANdw	NP_C2	PLA_C2	P_NLCD1_4+9
WaterSurfGrad	-0.16	-0.16	-0.11	0.37	0.10	-0.04	-0.09	0.11	-0.11	0.10
RipLU	.48	.51	.49	-.27	.17	.42	.46	-.20	.50	-.16
OCanAngleAvg	-.23	-.22	-.23	.14	.02	-.16	-.21	.08	-.23	.15
BFWidthNoPools	.12	.14	.10	-.31	-.29	.07	.01	.27	.09	.09
BFWidthDA	.53	.49	.52	-.11	-.16	.54	.60	**-.69**	.51	-.26
BFDepthNoPools	.15	.24	.17	-.47	.06	.17	.06	-.02	.16	-.41
BFDepthDA	.52	.52	.54	-.17	.11	.59	.61	**-.79**	.53	-.55
BFAreaNoPools	.18	.22	.17	-.43	-.23	.14	.06	.19	.15	-.08
BFAreaNoPoolsDA	.58	.58	.58	-.33	-.06	.58	.57	-.55	.57	-.44
BFWidthDepthNoPools	.05	.01	.01	-.08	-.41	-.02	-.03	.22	.00	.27
BFD$_{50}$crit	-.15	-.11	-.08	.21	.18	-.02	-.11	.16	-.08	-.03
GCUTypeRiffPct	.27	.23	.25	.05	.01	.29	.22	.11	.23	.02
GCUTypePoolPct	-.14	-.18	-.10	.40	-.34	-.07	-.13	.06	-.14	.21
GCUTypeRunPct	-.03	.03	-.05	-.39	.21	-.09	-.01	-.14	-.01	-.25
GCUTypePoolRiff	-.28	-.31	-.23	.38	-.27	-.23	-.28	.10	-.28	.17
DepthAvg	.08	.14	.11	-.23	-.17	.14	.04	-.08	.07	-.14
DepthMax	.21	.22	.24	-.09	-.42	.27	.19	-.12	.19	.04
RchVol	.08	.09	.06	-.16	-.26	.07	-.01	.17	.03	.12
WidthDepthAvg	.09	.04	.06	.06	-.19	.02	.04	.22	.06	.29
ChStab	.11	.11	.12	-.09	.18	.08	.12	-.10	.16	-.23
VelocAvg	.20	.21	.19	-.02	.10	.17	.20	.11	.20	-.08
DischM3Sec	.19	.19	.15	-.27	-.20	.11	.10	.18	.14	.09
DischargeDA	.40	.37	.34	-.31	-.18	.32	.35	-.16	.33	-.07
FinesPct	-.12	-.10	-.07	.12	.19	-.12	-.06	.01	-.08	.02
SiltCovPct	-.01	.02	-.01	-.10	.22	.04	.00	-.02	-.01	-.11
BedSubIndex	-.08	-.09	-.10	.15	-.01	-.03	-.10	.18	-.11	.08
EmbedPctAvg	-.07	-.03	-.04	-.10	.16	-.09	-.04	.00	-.02	-.07
BankVegCovPct	-.38	-.42	-.43	.33	-.15	-.33	-.47	.39	-.45	.28
BankErosPct	.21	.19	.18	.01	.29	.18	.21	-.19	.19	-.20
ErosionLengthAvg	.53	.51	.53	-.39	.05	.42	.53	-.19	.56	-.31

GIS characteristics											
pFORESTdw + pWETLdw	NP_C4+C9	PLA_C4+C9	NLCD_BIS	P_NLCD1_B4+B9	SQKM	PERL	P_TEXTURE3	P_HSG_2	PSRF2	P_FLAT	SLOPE_X
0.10	-0.03	0.09	-0.19	0.10	-0.08	0.22	0.15	0.14	0.03	-0.11	0.09
-.23	.00	-.32	.47	-.17	-.02	-.20	-.17	-.33	.19	-.23	.10
.08	.07	.13	-.15	.07	.05	.12	.14	.21	-.04	.13	-.02
.15	.47	.09	.13	.07	.54	-.08	.05	.14	.08	.01	-.04
-.33	-.61	-.34	.52	-.24	**-.73**	-.20	-.12	-.09	-.01	-.37	.20
-.24	.02	-.33	.23	-.34	.13	-.37	-.47	-.36	-.51	.42	-.49
-.57	**-.86**	-.59	.53	-.48	**-.93**	-.32	-.32	-.33	-.27	-.13	-.05
.02	.36	-.04	.22	-.06	.45	-.23	-.13	-.03	-.12	.11	-.17
-.41	-.44	-.47	.59	-.38	-.51	-.41	-.32	-.25	-.23	-.16	-.05
.25	.42	.21	.00	.19	.45	.08	.21	.27	.33	-.22	.18
.03	.01	-.02	-.13	-.03	.02	.12	-.02	.00	-.13	.06	-.09
-.01	.10	-.15	.16	.05	.06	.06	.02	.02	.08	-.19	.10
.11	.08	.28	-.22	.16	.03	.11	.20	.32	.46	-.26	.28
-.17	-.20	-.18	.09	-.23	-.08	-.13	-.25	-.32	-.43	.34	-.32
.11	.02	.30	-.32	.14	.07	.11	.13	.28	.36	-.07	.12
-.01	.10	-.05	.13	-.04	.11	-.21	-.09	.02	-.22	.14	-.18
.11	.12	.05	.17	.12	.05	-.18	.10	.21	.20	-.10	.08
.21	.40	.19	.09	.19	.37	-.02	.12	.21	.02	.04	-.01
.23	.38	.17	.02	.22	.34	.11	.26	.23	.44	-.26	.25
-.27	-.26	-.30	.12	-.31	-.17	-.12	-.25	-.32	-.03	-.08	-.02
-.11	.15	-.15	.17	-.01	.11	.17	.08	.00	.23	-.22	.20
.07	.43	.05	.17	.14	.40	-.08	.05	.03	.11	-.23	.16
-.12	.09	-.16	.35	.02	.01	-.17	-.02	-.08	.01	-.40	.25
.09	-.03	.10	-.06	.08	-.08	-.05	.10	.06	.09	.20	-.08
-.19	-.18	-.09	.07	-.19	-.08	.11	-.19	-.07	-.17	.54	-.39
.07	.04	.04	-.11	.07	.04	.29	-.02	-.01	-.18	-.07	.01
-.05	.01	.05	.02	-.05	.08	-.16	.05	-.03	.03	.19	-.07
.28	.22	.36	-.41	.21	.20	.34	.25	.26	-.10	.15	.08
-.17	-.17	-.23	.13	-.11	-.22	-.02	-.15	-.18	-.13	.26	-.17
-.28	-.07	-.31	.48	-.20	-.03	-.33	-.14	-.24	.22	-.18	.05

Table 7. Spearman rank correlations between reduced habitat/habitat characteristics for 30 sites in the Milwaukee to Green Bay, Wis., study area.

[For individual correlations, n = 30, for p ≤ 0.001, rho = 0.580 (dark green); for p ≤ 0.01, rho = 0.467 (green); for p ≤ 0.05, 0.362 (light green); with Bonferroni adjustments for multiple tests (53), the critical rho is 0.66 for a p-value of 0.05. Correlations greater than the Bonferroni adjustment are in **bold**. Characteristic definitions are listed in appendixes 1–4.]

Habitat characteristic abbreviations	Habitat characteristics												
	WaterSurfGrad	RipLU	OCanAngleAvg	BFWidthNoPools	BFWidthDA	BFDepthNoPools	BFDepthDA	BFAreaNoPools	BFAreaNoPoolsDA	BFWidthDepth-NoPools	BFD50crit	GCUTypeRiffPct	GCUTypePoolPct
WaterSurfGrad	1.00												
RipLU	.13	1.00											
OCanAngleAvg	-.08	-.07	1.00										
BFWidthNoPools	-.01	.24	-.11	1.00									
BFWidthDA	.04	.19	-.11	.09	1.00								
BFDepthNoPools	-.25	-.15	-.06	.40	.00	1.00							
BFDepthDA	-.05	-.03	-.02	-.39	**.74**	.18	1.00						
BFAreaNoPools	-.15	.10	-.15	**.93**	.10	**.69**	-.21	1.00					
BFAreaNoPoolsDA	-.05	.17	-.19	.35	**.84**	.47	**.68**	.48	1.00				
BFWidthDepthNoPools	.18	.37	-.09	**.81**	.13	-.13	-.48	.58	.12	1.00			
$BFD_{50}crit$	**.95**	.12	-.08	.12	-.03	.01	-.06	.04	.04	.18	1.00		
GCUTypeRiffPct	.50	.42	-.21	.28	.08	-.06	-.08	.19	.12	.44	.50	1.00	
GCUTypePoolPct	.31	-.07	-.05	.14	.06	-.17	-.12	.02	-.03	.32	.22	.19	1.00
GCUTypeRunPct	-.50	-.25	.11	-.26	-.10	.20	.18	-.10	-.04	-.49	-.42	-.65	**-.82**
GCUTypePoolRiff	.13	-.28	.01	-.02	-.10	-.16	-.15	-.09	-.19	.12	.06	-.10	**.89**
DepthAvg	-.19	-.37	.13	.38	.08	**.73**	.13	.58	.34	-.01	-.06	-.13	.10
DepthMax	.03	-.06	-.10	.52	.27	.43	.06	.59	.37	.36	.07	.10	.35
RchVol	-.16	-.18	.09	**.72**	.07	.59	-.17	.81	.32	.41	-.05	.05	.14
WidthDepthAvg	.23	.54	-.07	.57	.09	-.36	-.45	.31	.00	**.87**	.18	.57	.24
ChStab	.13	.48	-.38	-.20	.05	-.32	.05	-.29	.01	.00	.11	.20	-.12
VelocAvg	.11	.24	-.18	.27	-.02	.07	-.09	.26	.07	.26	.12	.60	.14
DischM3Sec	-.19	.16	-.08	.62	-.07	.45	-.22	.70	.18	.39	-.11	.32	.09
DischargeDA	-.25	.15	-.05	.39	.21	.39	.16	.51	.37	.19	-.21	.28	-.02
FinesPct	-.43	-.23	.20	-.51	-.22	-.16	.04	-.45	-.32	-.55	-.50	-.61	-.20
SiltCovPct	-.35	-.25	.15	-.35	-.11	.02	.11	-.28	-.14	-.44	-.32	-.33	-.35
BedSubIndex	.63	.17	-.17	.27	.13	.15	.00	.26	.20	.31	**.68**	**.72**	.12
EmbedPctAvg	-.56	-.17	.18	-.36	-.33	-.11	-.07	-.32	-.34	-.47	-.59	**-.72**	-.30
BankVegCovPct	-.14	-.25	.53	.06	-.22	.21	-.14	.11	-.13	-.03	-.08	-.02	.17
BankErosPct	-.29	-.14	-.21	-.46	-.19	.06	.18	-.38	-.15	-.57	-.27	-.19	-.24
ErosionLengthAvg	-.09	.35	-.54	.15	.05	-.06	.00	.11	.12	.11	-.12	.05	-.06

Habitat characteristics																
GCUTypeRunPct	GCUTypePoolRiff	DepthAvg	DepthMax	RchVol	WidthDepthAvg	ChStab	VelocAvg	DischM3Sec	DischargeDA	FinesPct	SiltCovPct	BedSubIndex	EmbedPctAvg	BankVegCovPct	BankErosPct	ErosionLengthAvg
1.00																
-.54	1.00															
.01	.05	1.00														
-.32	.18	**.74**	1.00													
-.14	.03	**.85**	**.76**	1.00												
-.52	.00	-.31	.12	.12	1.00											
-.01	-.10	**-.81**	-.60	**-.76**	.22	1.00										
-.42	-.10	.13	.13	.26	.34	-.05	1.00									
-.22	-.08	.53	.47	**.72**	.24	-.41	.63	1.00								
-.09	-.19	.51	.41	.59	.07	-.39	.63	**.89**	1.00							
.39	.03	-.03	-.16	-.20	-.47	-.11	-.43	-.36	-.31	1.00						
.48	-.14	-.17	-.39	-.30	-.43	.09	-.44	-.49	-.46	.35	1.00					
-.42	-.09	.00	.10	.14	.31	.07	.40	.27	.21	**-.75**	-.30	1.00				
.54	-.05	-.07	-.29	-.24	-.47	.00	-.38	-.27	-.27	**.81**	.41	**-.87**	1.00			
-.11	.18	.18	-.01	.26	-.02	-.30	.00	.10	.01	-.10	.04	.18	-.12	1.00		
.28	-.11	-.07	-.26	-.28	-.48	.14	-.09	-.33	-.20	.44	.43	-.40	.43	-.08	1.00	
.02	-.08	-.13	.11	-.06	.05	.29	.18	.18	.21	.17	-.15	-.28	.25	-.64	.24	1.00

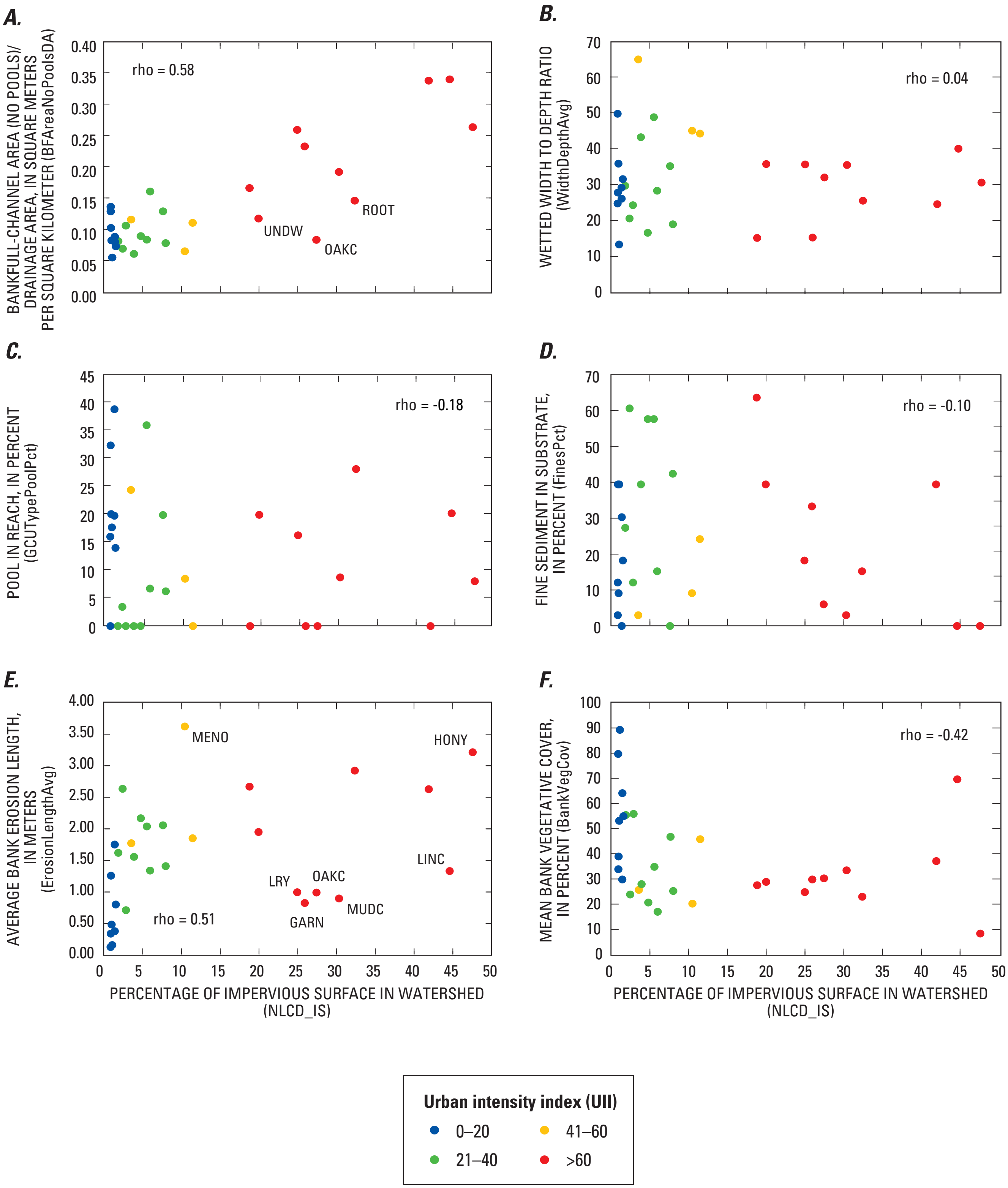


Figure 17. Relations between percent impervious surface in the watershed and selected habitat characteristics for 30 study sites in the Milwaukee to Green Bay, Wis., study area.

Geomorphic-channel units, such as riffles, do not appear to be influenced by urbanization (fig. 17*C*, table 6). Instead, the percentage of riffles correlated with reach slope (fig. 18). Even relatively subtle (0.5 percent) changes in slope affected the amount of riffles (similar to Chicago-area streams, Fitzpatrick and others, 2005). Other studies in Wisconsin and across the U.S. reported similar findings (Wang and others, 1997; Wang and others, 2000; Wang and others, 2001; Walters and others, 2005).

Similar to the percentage of riffles, streambed-substrate size, silt coverage, and embeddedness correlated with reach slope and not with urbanization (tables 6 and 7, fig. 17*D*). Chicago-area streams showed similar relations (Fitzpatrick and others, 2005). Relatively high velocity, large substrates, and low embeddedness were found in streams with high percentages of riffles (table 7). Some studies have shown a shift to finer substrates with increasing urbanization (MacCoy and Blew, 2005; Roy and others, 2006). Geomorphic responses to urbanization, however, are highly variable in space and time (Gregory and Madew, 1982). A combination of other environmental factors in addition to changes in runoff—slope, position within the stream network, base level, phase of development, channel-boundary conditions, local sediment-transport characteristics, proximity to geomorphic thresholds, and disturbance history—is usually responsible for determining whether the geomorphic response to urbanization is erosional or depositional (Knight, 1979; Bledsoe and Watson, 2001; Fitzpatrick and others, 2006).

Bank stability (represented by indicators of bank erosion for this study) can be influenced by watershed and local factors (tables 6 and 7). Average length of bank erosion (ErosionLengthAvg) correlated to urban indicators such as the UII, watershed impervious surface, watershed urban land, and distance to nearest urban land (table 6, figs. 17*E* and 17*F*). The relation was strongest for sites with less than 20 to 25 percent watershed impervious surface (fig. 17*E*). Variable amounts of bank erosion were found in sites with greater than 20 to 25 percent watershed impervious surface. Low bank-erosion lengths were found in some urban sites (such as Oak Creek, Mud Creek, Garners Creek, Lily Creek, and Lincoln Creek). Garners Creek, Lily Creek, and Lincoln Creek are engineered channels with abundant rip rap associated with bank protection and grade control. Low average bank-erosion lengths were found at Mud Creek and Oak Creek where there was no evidence of bank stabilization or grade control. Mud Creek banks, however, are lined with residential lawns on both sides, suggesting historical bank protection. Oak Creek was channelized; rock riffles may have provided historical grade control. Menomonee River and Honey Creek had high average bank erosion lengths and had actively failing bank stabilization. These results indicate the importance of knowing the stabilization history for the reach as well as for upstream and downstream areas.

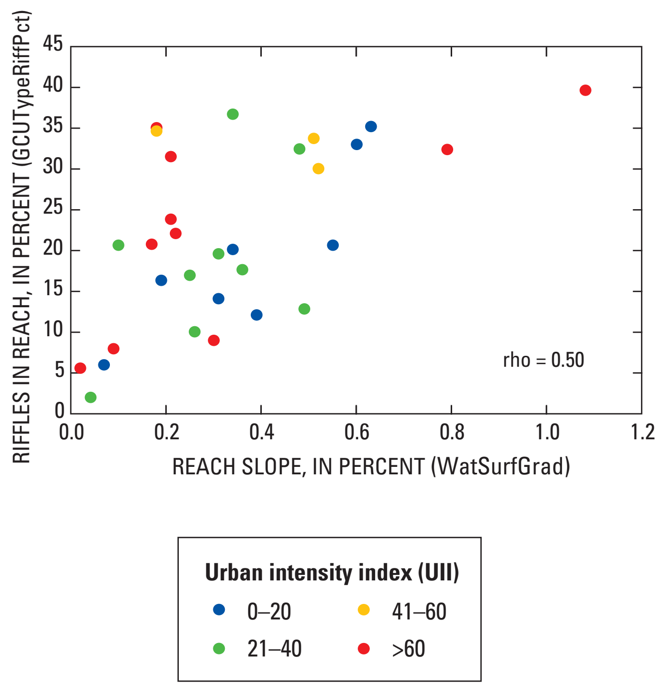


Figure 18. Relation between reach slope and percentage of riffles in reach for 30 study sites in the Milwaukee to Green Bay, Wis., study area.

Measures of bank erosion can be misleading if all factors are not considered. For example, there were small canopy angles for channels with high lengths of bank erosion and less bank vegetation, suggesting more erosion at tree-lined banks (table 7). As stated earlier, however, the lack of vegetation is not a direct surrogate for the amount of erosion. Tree-lined banks tend to be less vegetated with more exposed soil and trees tend to cause local scour when the bank fails; therefore more bank erosion is assumed (Lyons and others, 2000). Tree roots, however, extend deeper than herbaceous vegetation and add more resistance to erosion (Simon and Collison, 2002). Slumping along grassy banks is masked quickly by new vegetation growth. Thus, assumptions of erosion based on vegetation cover or exposed soil must be considered as estimates only.

The general lack of strong correlations of other habitat characteristics with urbanization in the Milwaukee/Green Bay areas further supports the findings of other studies that suggest commonly measured habitat characteristics (except those related to bankfull-channel size) are inadequate for detecting geomorphic responses caused by urbanization (Booth and Jackson, 1997; Fitzpatrick and others, 2005; Short and others, 2005; Walters and others, 2005; Sprague and others 2006). Variations in geomorphic-channel units and streambed substrate for Milwaukee/Green Bay are caused more likely by local variations in geologic setting, slope, and watershed topography, and river engineering practices than by watershed land-cover disturbance. River engineering practices such as channelization cause habitat changes over short time scales and local lengths of the stream network; watershed land-cover changes can take decades or centuries and require significant lengths of the stream network to be altered.

If a goal of the habitat study is to identify habitat responses to urbanization, then the type, amount, and age of channel modifications need to be recognized because of the important ramifications that river engineering practices have for affecting the geomorphic-response potential of streams to urbanization. For this study, field comments regarding channel modifications were supplemented after sampling with additional evidence from USGS quadrangle maps, aerial photographs, photographs of the reach and transects taken during the sampling, and occurrence of riprap/irregular bedrock for bank and streambed substrate. Biostabilization is a popular technique for controlling bank erosion, which is purposefully made to look as natural as possible; it becomes a further challenge for field crews to detect. The most obvious bank-stabilization and grade-control features in this study were either less than 2 years or likely more than a few decades old. For future studies, it would be helpful for field crews to receive training to identify bank stabilization techniques. Additionally, it would be helpful to have information on grade controls immediately upstream or downstream from the reach, which affect the local base level and ultimately control the potential geomorphic responses to upstream changes in runoff and sediment.

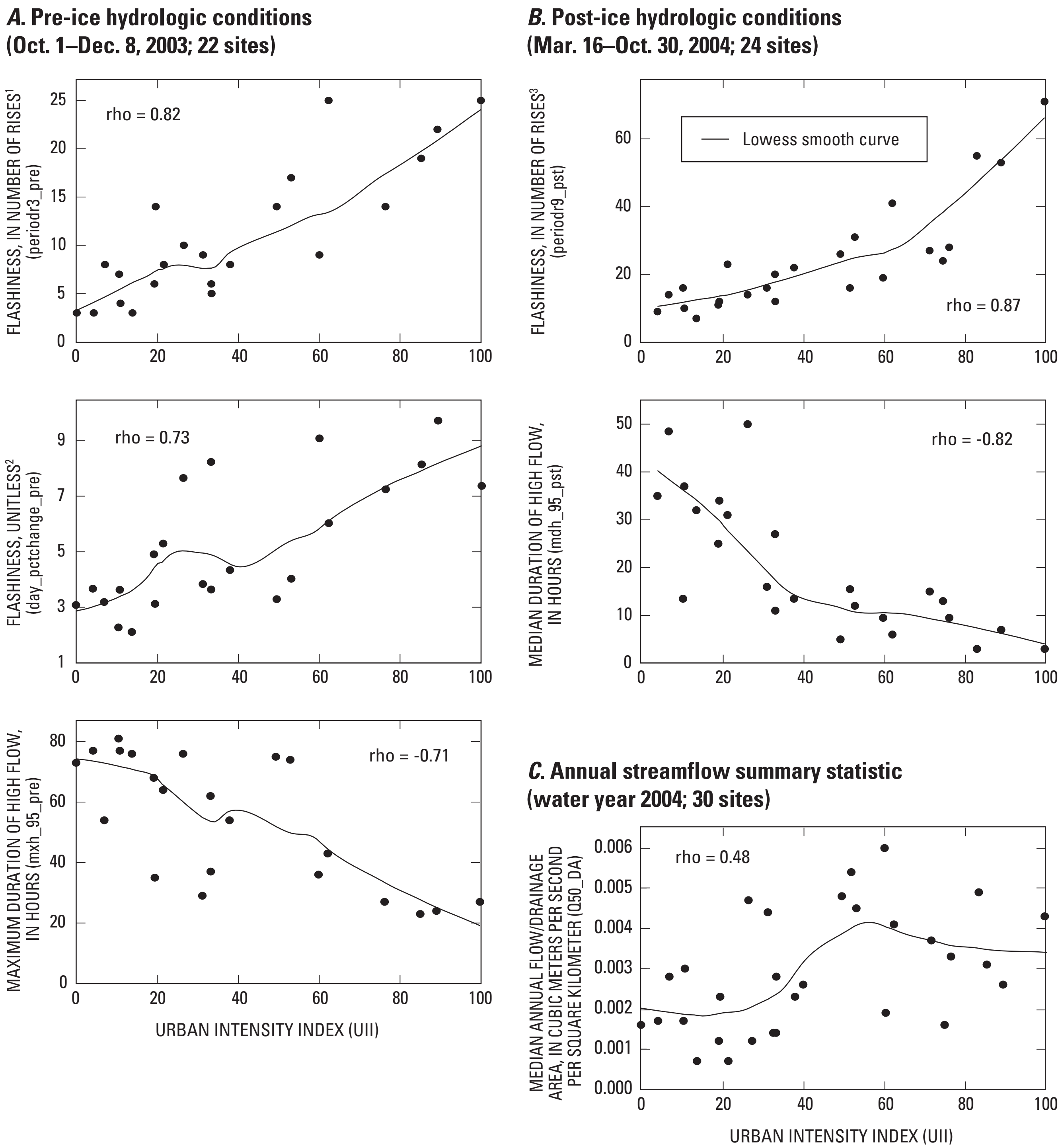
Hydrology

Impacts from urbanization often have more-severe effects on hydrology than do logging or agriculture. A city block with a high percentage of impervious surfaces such as rooftops, roads, and parking lots generates more than five times more runoff than a woodland area of the same size (U.S. Environmental Protection Agency, 2003). To determine whether flow or area should form the basis of the hydrologic-condition metrics (HCM; a, area based; q, flow based), an initial comparison was conducted between the two sets of metrics with a subset of 16 biological (algal, invertebrate, fish) metrics. Spearman's rho was greater than or equal to 0.5 for 72 pre-ice HCMa-biology and 54 post-ice HCMa-biology relations. About one-half as many correlations were present at that level for discharge-based hydrologic-condition metrics (HCMq); there were 35 pre-ice HCMq-biology and 26 post-ice HCMq-biology relations with rho >0.5. At the eight established USGS streamflow-gaging stations with higher quality stage-discharge rating curves, the opposite was true: the flow-based HCMq correlation with the biological metrics was stronger than the area-based HCMa. Twenty percent more rho values >0.71 were present for HCMq than for HCMa. This is a preliminary indication that flow-based HCMq may be more useful than area-based HCMa, provided quality streamflow data are built upon established stage-discharge rating curves. For this study, however, in which temporary pressure transducers were present at 22 of 30 sites, area-based HCMa performed better than flow-based HCMq. Therefore, based upon this initial finding, the remainder of these analyses and discussion use area-based hydrologic condition metrics (HCMa).

Of the HCMa, the flashiness metrics and the duration of high flow were the most strongly correlated to the UII (table 8). A strong positive relation with the UII (rho = 0.87; fig. 19*B*) was present with the HCMa metric periodr9 (an indicator of frequent substantial hydrograph rises), during the post-ice period, March 16 to October 30. During the same post-ice period, the median duration of high-flow events (MDH_95) was negatively correlated with the UII (rho = -0.82; fig. 19*B*).

Several HCMa metrics computed during the pre-ice period correlated with the UII, but the specific metrics differed from the post-ice period. Stream flashiness again was associated positively with urban development; periodr3_pre was the most significant metric (rho = 0.82; fig. 19*A*). Although not as strongly correlated as the periodr3_pre metric, the rho for the flashiness metric built upon daily as opposed to hourly data, day_pctchange_pre, was 0.73 (fig. 19*A*). The maximum duration of high flow (MXH_95) also was inversely correlated with urbanization during this period (rho = -0.71; fig. 19*A*). These findings are consistent with previous studies, indicating urbanization often promotes frequent, steep hydrograph rises and shorter high-flow durations.

Two sites with similar UII values were selected to provide a comparison of the area-based flashiness metric, periodr9_pst and illustrate discharge characteristics. The UII for Black Otter Creek is slightly higher (26.5) than Ashwaubenon Creek (21.5), but Black Otter Creek is a less flashy-stream (fig. 20*A*). The visual flashiness of the pressure transducer cross-sectional area time series is quantified with the metric periodr9_pst. Twenty-three times, the pressure transducer's cross-sectional area increased by at least 0.9 m^2 (9 times the median area rise of 0.1 m^2) at Ashwaubenon Creek, while at Black Otter Creek, the pressure transducer's cross-sectional area increased by at least 0.9 m^2 14 times (Black Otter Creek median area rise was also 0.1 m^2). An impoundment is just upstream from the sampled reach at Black Otter Creek; there were a higher percentage of Black Otter Creek watershed in wetlands than Ashwaubenon Creek (appendix 7—two factors that likely contribute to a less-flashy stream (reduced periodr9).



[1] When total rise of cross-sectional area is greater than or equal to 3 times the median total rise over the pre-ice period of record (Oct. 1–Dec. 8, 2003).

[2] Sum of the absolute values of the relative change in cross-sectional area from the pre-ice period of record (Oct. 1–Dec. 8, 2003).

[3] When total rise of cross-sectional area is greater than or equal to 9 times the median total rise over the post-ice period of record (Mar. 16–Oct. 20, 2004).

Figure 19. Relations between urban intensity index (UII) and hydrologic metrics for *A*, pre-ice (October 1–December 8, 2003), *B*, post-ice (March 16–October 30, 2004) conditions, and *C*, annual streamflow-summary statistic for water year 2004 for the Miwaukee to Green Bay, Wis., study area.

Table 8. Summary of maximum Spearman rank correlations between reduced hydrology (area-based hydrologic-condition characteristics and annual streamflow-summary statistics) and three biological groups and the urban intensity index for 30 sites in the Milwaukee to Green Bay, Wis., study area.

[DA, drainage area; UII, urban intensity index. Pre-ice (October 1 to December 8, 2003) hydrologic condition metrics are area based; n=22; for $p \leq 0.001$ rho = 0.667 (dark green), for $p \leq 0.01$ rho = 0.544 (light green); Post-ice (March 16 to October 30, 2004) hydrologic condition metrics are area based; n=24; $p = 0.001$ rho = 0.642, for $p \leq 0.01$ rho = 0.521; Annual streamflow-summary statistics are flow based, n = 30; for $p \leq 0.001$ rho = 0.580, for $p \leq .01$ rho = 0.467. UII, Urban intensity index. Metric definitions listed in appendix 1-5; metric suffixes "pre" and "pst" refer to pre-ice and post-ice periods, respectively.]

Metric abbreviation	Definition	Fish			Invertebrates			Algae			UII (rho value)
		Number of relations significant at $p \leq 0.01$	Number of relations significant at $p \leq 0.001$	Rho values[1]	Number of relations significant at $p \leq 0.01$	Number of relations significant at $p \leq 0.001$	Rho values[2]	Number of relations significant at $p \leq 0.01$	Number of relations significant at $p \leq 0.001$	Rho values[3]	
Pre-ice period (Oct. 1–Dec. 8, 2003) hydrologic-condition metrics, area based; n=22											
pct_25n_pre	Low area (flow) magnitude	0	0	-0.43	8	0	0.62	3	0	0.60	0.05
pct_5n	Low area (flow) magnitude	0	0	-.45	10	2	.69	1	0	.58	-.08
pct_95a	High area (flow) magnitude	0	0	.42	0	0	.53	2	1	.68	.01
day_pctchange_pre	Flashiness indicator	8	1	-.69	7	1	-.69	3	1	.71	.73
max_torise_pre	Flashiness indicator	0	0	.43	0	0	-.54	7	0	.65	.37
periodr1_pre	Flashiness indicator	0	0	.46	5	0	.62	0	0	.50	-.23
periodr3_pre	Flashiness indicator	0	0	-.53	5	0	-.63	4	1	.69	.82
periodf3_pre	Flashiness indicator	2	0	-.56	1	0	-.64	14	7	.73	.81
max_durfall_pre	Flashiness indicator	3	0	.57	0	0	.36	3	0	.64	.39
MXH_95_pre	Duration high-flow indicator	2	1	.61	1	0	.55	1	0	-.55	-.71
MDH_95_pre	Duration high-flow indicator	1	0	.56	10	1	.67	0	0	.44	-.64
MXL_25_pre	Duration low-flow indicator	0	0	.40	2	1	-.69	0	0	-.42	.10
MXL_10_pre	Duration low-flow indicator	1	0	.63	0	0	-.45	0	0	.49	.27
Post-ice period (Mar. 16–Oct. 30, 2004) hydrologic-condition metrics, area based; n=24											
pct_99n_pst	High area (flow) magnitude	1	0	-0.53	4	1	-0.65	1	0	-0.55	0.30
pct_25a_pst	Low area (flow) magnitude	0	0	.33	5	1	.65	1	0	.53	-.23
day_pctchange_pst	Flashiness indicator	0	0	-.50	5	1	-.73	0	0	-.48	.55
periodr1_pst	Flashiness indicator	7	2	.69	5	1	-.64	9	0	-.60	-.29
periodr9_pst	Flashiness indicator	4	0	-.64	3	0	-.59	13	8	.71	.87

[1] This value represents the highest Spearman rank correlation coefficient (rho value) for each metric when compared with 53 fish characteristics. Shaded values are statistically significant.

[2] This value represents the highest Spearman rank correlation coefficient (rho value) for each metric when compared with 133 benthic macroinvertebrate characteristics. Shaded values are statistically significant.

[3] This value represents the highest Spearman rank correlation coefficient (rho value) for each metric when compared with 112 algal characteristics. Shaded values are statistically significant.

Table 8. Summary of maximum Spearman rank correlations between reduced hydrology (area-based hydrologic-condition characteristics and annual streamflow-summary statistics) and three biological groups and the urban intensity index for 30 sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[DA, drainage area; UII, urban intensity index. Pre-ice (October 1 to December 8, 2003) hydrologic condition metrics are area based; n=22; for p ≤ 0.001 rho = 0.667 (dark green), for p ≤ 0.01 rho = 0.544 (light green); Post-ice (March 16 to October 30, 2004) hydrologic condition metrics are area based; n=24; p =0.001 rho = 0.642, for p ≤ 0.01 rho = 0.521; Annual streamflow-summary statistics are flow based, n = 30; for p ≤ 0.001 rho = 0.580, for p ≤ 0.01 rho = 0.467. Metric definitions listed in appendix 1-5; metric suffixes "pre" and "pst" refer to pre-ice and post-ice periods, respectively.]

Metric abbreviation	Definition	Fish			Invertebrates			Algae			UII (rho value)
		Number of relations significant at p ≤ 0.01	Number of relations significant at p ≤ 0.001	Rho values[1]	Number of relations significant at p ≤ 0.01	Number of relations significant at p ≤ 0.001	Rho values[2]	Number of relations significant at p ≤ 0.01	Number of relations significant at p ≤ 0.001	Rho values[3]	
periodfl_pst	Flashiness indicator	3	0	.59	6	3	.72	0	0	.45	-.17
Post-ice period (Mar. 16–Oct. 30, 2004) hydrologic-condition metrics, area based; n=24—Continued											
MXH_95_pst	Duration high-flow indicator	0	0	0.48	13	2	-0.71	3	0	-0.61	-0.04
MDH_90_pst	Duration high-flow indicator	3	1	.67	1	0	.56	0	0	-.41	-.71
MDH_95_pst	Duration high-flow indicator	1	1	.68	2	0	.61	2	0	-.55	-.82
MXL_10_pst	Duration low-flow indicator	0	0	.48	3	1	.69	1	0	-.55	-.32
MXL_5_pst	Duration low-flow indicator	0	0	.49	6	2	.75	0	0	-.52	-.29
Annual streamflow-summary statistics; n = 30											
Q_bnkfl	High flow	4	1	-0.62	2	0	-0.48	0	0	0.43	0.15
Q_max	High flow - daily maximum	0	0	.40	3	1	-.59	6	0	-.51	-.10
Q_10	High flow - 10 percent exceed	0	0	-.36	3	2	-.61	1	0	-.48	-.19
Q_50	Median flow	0	0	-.43	13	1	.64	5	0	-.56	.09
Q_90	Low flow - 90 percent exceed	0	0	.40	8	4	.62	0	0	-.46	.09
Q_bnkflDA	High flow (modeled)/ DA	1	1	-.67	3	0	-.54	0	0	.36	.42
Qmax_instDA	Instantaneous high flow/DA	6	0	-.56	5	0	-.54	1	0	.55	.45
Q_50DA	Median flow/DA	1	0	.55	13	2	-.59	0	0	-.40	.49
Urban Intensity Index (UII); n = 30											
UII	Urban intensity index	3	1	-0.61	11	2	-0.68	9	5	0.62	1.00

[1] This value represents the highest Spearman rank correlation coefficient (rho value) for each metric when compared with 53 fish characteristics. Shaded values are statistically significant.

[2] This value represents the highest Spearman rank correlation coefficient (rho value) for each metric when compared with 133 benthic macroinvertebrate characteristics. Shaded values are statistically significant.

[3] This value represents the highest Spearman rank correlation coefficient (rho value) for each metric when compared with 112 algal characteristics. Shaded values are statistically significant.

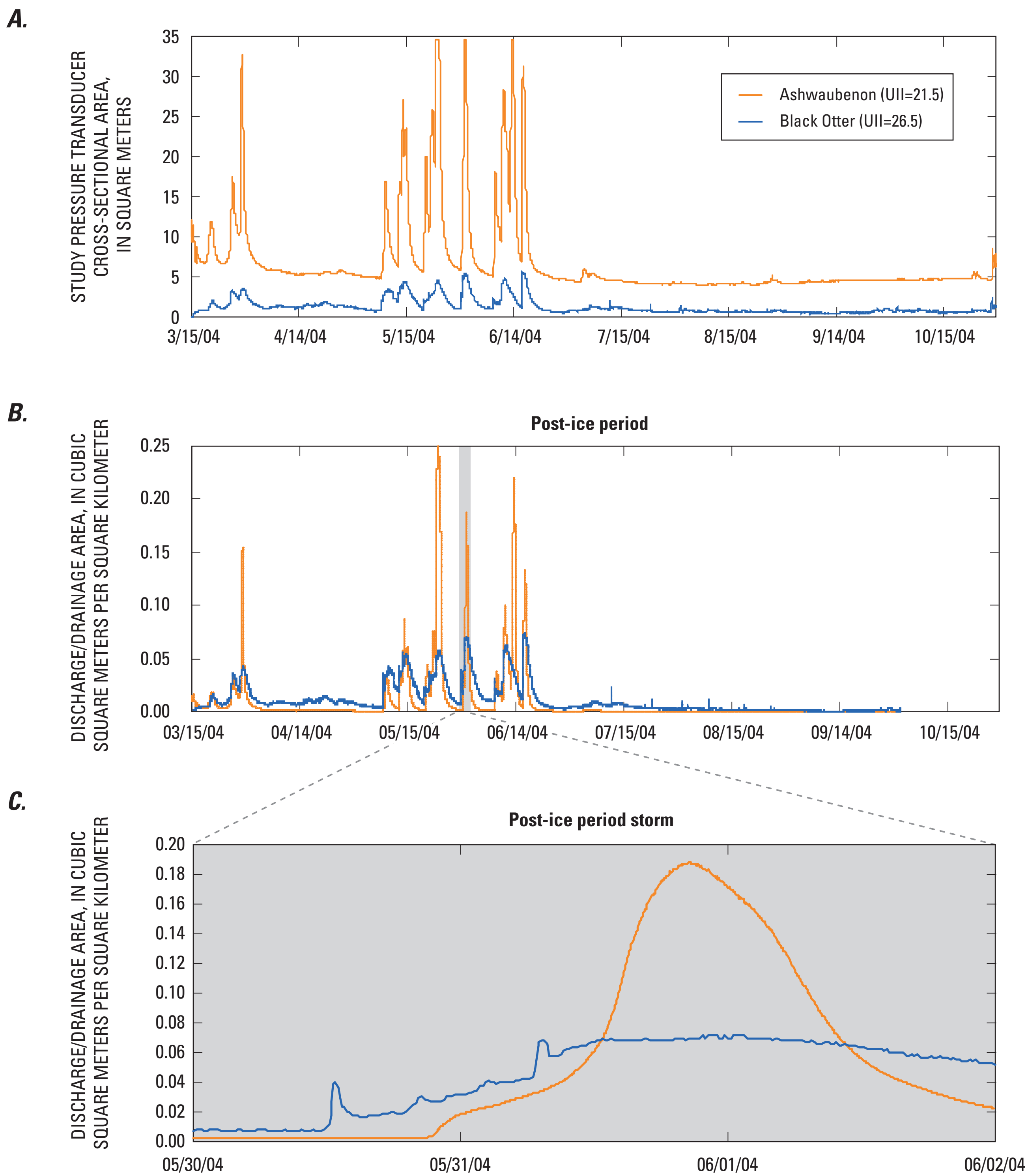


Figure 20. *A*, Pressure transducer cross-sectional area and *B*, hydrographs for the Ashwaubenon Creek at South Bridge Road near Depere, Wis., and the Black Otter Creek near Hortonville, Wis., sites during the post-ice period, March 16–October 30, 2004, and *C*, a post-ice period storm.

Although the pressure-transducer area time series is easier to obtain than a discharge record, the area-time series is an approximation of the discharge hydrograph. Both stream sites are in the northern section of the study area and are assumed to receive similar precipitation. In the discharge record (as in area time series), the peak flow/area was greater for Ashwaubenon Creek than for Black Otter Creek (fig. 20*B*); Black Otter Creek base flow (Q90 = 0.057 m^3/s), however, is more than 10 times greater than that of Ashwaubenon Creek (Q90=0.004 m^3/s). The increased Black Otter Creek base flow also may be a result of the impoundment and wetland area.

An expansion of the May 31 high flow illustrates that, although the overall Black Otter Creek hydrograph is dampened, small hydrograph pulses appear at the beginning of storms (fig. 20*C*). These small hydrograph pulses could be a result of urbanization in the immediate vicinity of the sampling site (appendix 7). The annual streamflow-summary statistics, which also were computed on daily flow data, showed no significant relations with urbanization at $p<0.001$ (table 8). The annual median flow normalized by drainage area (Q50_DA) correlated with urbanization, indicating that median flow increased with urban development (rho = 0.48; fig. 19*C*).

Several of the duration and flashiness metrics during the pre- and post-ice periods display a slope change in the UII relations at a value of 30 to 60 (fig. 19*A*, *B*). The median annual-flow summary statistic (Q50) relation with urbanization showed a less-distinct slope change (fig. 19*C*). The UII values from 30 to 60 correspond to watershed impervious surface of 5 to 10 percent.

Spearman rank correlations were used to identify relations between the hydrologic characteristics and a subset of the GIS watershed variables to gain insight into factors that may drive the selected hydrologic characteristics (table 8). This 155-variable GIS subset consisted primarily of overall watershed, riparian and stream segment, distance-weighted, and patchiness land-cover variables. A large number (121) of these potentially management-related or controllable GIS variables were correlated with one or more of the reduced hydrologic characteristics at a significance of $p<0.01$ (table 9).

The hydrologic-soils variable for high infiltration (4-8 mm/hr; P_HSG_2) showed a weak negative relation with urban development (rho = -0.38); there was a negative association (rho = -0.70) with stream flashiness (day_pctchange) in the pre-ice period. As might be expected, but providing further confidence in the watershed GIS hydrologic-condition metric relations, soils with lower infiltration rates (0-1 mm/hr; P_HSG_4) also were associated with increased annual median streamflow (Q50) (table 9).

The percentages of forest (P_NLCD1_4) and wetland (P_NLCD1_9) land cover in the watershed were more closely related (more relations at $p>0.01$) to hydrologic-condition metrics computed in the pre-ice (October to December) period than in the post-ice period (March to October). This further supports the concept that the pre-ice period may be an interval when the natural flow regime, of which vegetation plays a role, may be discerned more readily (Poff and others, 1997).

Increased percentage of wetland land cover (P_NLCD1_9) in the watershed was associated with reduced flashiness and extended periods of higher flows—hydrologic traits of the natural flow regime. For example, increased wetland land cover was associated with lower stream flashiness (day_pctchange_pre [rho = -0.73], periodf3_pre [rho = -0.72]) and increased flow duration (mxh_95_pre, rho = 0.69) (table 9). Stream flashiness was reduced when the percentage of wetland in the watershed was greater than ~3 percent (fig. 21*A*). Similar relations between forest land cover were present with these hydrologic-condition metrics although the relation was not as strong as the percentage of wetland in the watershed. There was negative correlation between the percentage of forest and wetland variables with developed land cover in the watershed (P_NLCD1_2) (rho = -0.54 and -0.66, respectively).

Further, land-cover shape, patchiness, and distribution were related to hydrologic-condition metrics. The forest and wetland fragstat variables (_C4 and _C9 suffixes; table 9) were strongly associated with hydrologic-condition metrics computed in the pre-ice period, as compared to the post-ice period. Watersheds with wetland patches surrounded by other types of patches (low PLA_C9 value) showed increased stream flashiness (periodf3_pre [rho = -0.72]) and prolonged higher flow (mxh_95_pre [rho = 0.69]) (table 9). Although identical Spearman correlations with stream flashiness percentage of wetland land cover and wetland like adjacent (or wetland isolation; PLA_C9) were present, the wetland isolation metric showed a stronger linear relation (rho = -0.72) with stream flashiness (fig. 21*B*).

Stream flashiness decreased with increasing forest-shape index values (SIM_C4). The relation between forest elongation and reduced flashiness (fig. 21*C*; rho = -0.73) was greater than the relation between watershed forest land cover (PNLCD_4) and stream flashiness (periodr3_pre) relation (rho = -0.58) (table 9).

An increase in the size of wetland patches (PAM_C9) and an increase in wetland-like adjacencies (PLA_C9), meaning less wetland isolation, were associated with reduced bankfull flow (Q_bnkflDA) and instantaneous discharge as normalized by drainage area (Qmax_instDA) (table 9; fig. 21*D*). The correlation between percentage of wetland in the watershed was less with these two high-flow characteristics (rho = -0.45, -0.54, respectively) (table 9) than with the wetland fragstat variables (PAM_C9 and PLA_C9).

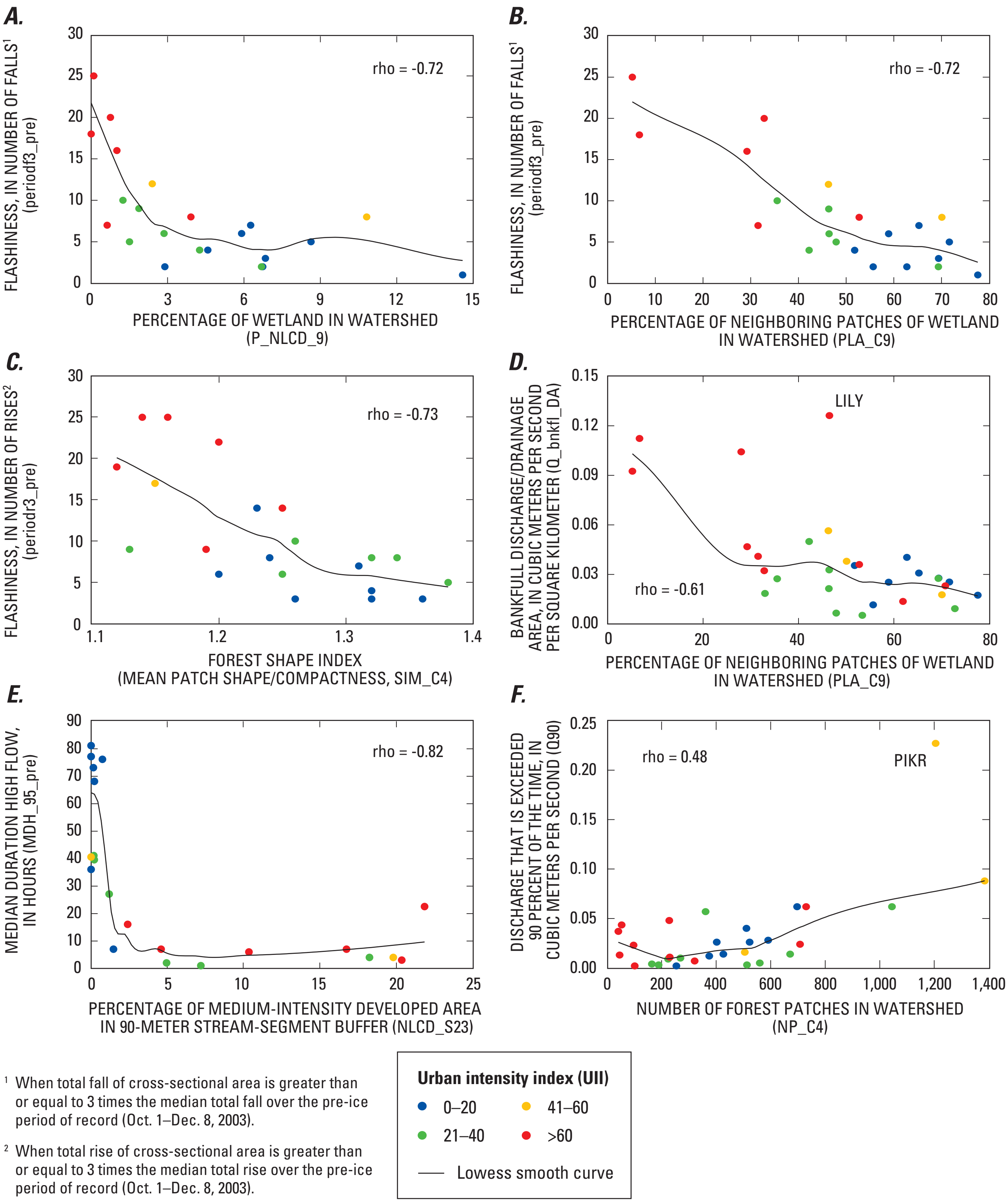
Table 9. Spearman rank correlations between reduced hydrology and selected geographic information system (GIS) derived characteristics[1] and the urban intensity index (UII) for 30 sites in the Milwaukee to Green Bay Wis., study area.

[mm/hr, millimeters per hour; UII, urban intensity index. Pre-ice hydrologic-condition metrics, for p ≤ 0.001, rho = .667 (dark green); for p ≤ 0.01, rho = 0.544 (light green). Post-ice hydrologic-condition metrics, for p ≤ 0.001, rho = 0.642 (dark green); for p ≤ 0.01, rho = 0.521 (light green). Annual streamflow-summary statistics, for p ≤ 0.001, rho = 0.580 (dark green); for p ≤ 0.01, rho = 0.467 (light green). Characteristic definitions are listed in appendixes 1-2 and 1-5.]

Characteristic abbreviation	UII	Hydrologic soils group: Infiltration rate, 4–8 mm/hr	Hydrologic soils group: Infiltration rate, 0–1 mm/hr	Watershed land cover: Impervious	Watershed land cover: Developed	Watershed land cover: Forest	Watershed land cover: Wetland
		P_HSG_2	P_HSG_4	NLCD_IS	P_NLCD1_2	P_NLCD1_4	P_NLCD1_9
UII	1.00	-0.38	0.11	0.96	0.97	-0.46	-0.61
Pre-ice period (Oct. 1–Dec. 8, 2003) hydrologic-condition metrics, area based; n=22							
pct_25n_pre	0.05	0.04	-0.24	0.10	0.06	-0.17	-0.25
pct_5n_pre	-.08	.12	-.05	-.04	-.07	-.13	-.16
pct_95a_pre	.01	-.19	.22	.01	-.01	-.22	-.13
day_pctchange_pre	.73	-.70	-.03	.75	.75	-.62	-.73
max_torise_pre	.37	-.41	-.23	.42	.43	-.62	-.64
periodr1_pre	-.23	.10	.24	-.24	-.27	-.10	.13
periodr3_pre	.82	-.63	.37	.81	.79	-.58	-.55
periodf3_pre	.81	-.59	.11	.82	.82	-.65	-.72
max_durfall_pre	.39	-.47	-.02	.44	.45	-.36	-.55
MXH_95_pre	-.71	.57	.18	-.74	-.75	.54	.69
MDH_95_pre	-.64	.31	-.10	-.64	-.62	.15	.37
MXL_25_pre	.10	-.13	.10	.01	.01	.03	.08
MXL_10_pre	.27	-.49	.22	.27	.28	-.29	-.24
Post-ice period (Mar. 16–Oct. 30, 2004) hydrologic-condition metrics, area based; n=24							
pct_99n_pst	0.30	-0.18	-0.07	0.26	0.28	-0.15	-0.16
pct_25a_pst	-.23	.03	.08	-.19	-.22	.04	.12
day_pctchange_pst	.55	-.31	.07	.52	.51	-.27	-.40
periodr1_pst	-.29	.29	-.16	-.31	-.28	.12	.25
periodr9_pst	.87	-.48	.35	.90	.88	-.48	-.59
periodf1_pst	-.17	.12	-.14	-.15	-.13	-.03	.13
MXH_95_pst	-.04	.25	.16	-.13	-.09	.24	.48
MDH_90_pst	-.71	.27	-.34	-.70	-.69	.34	.36
MDH_95_pst	-.82	.21	-.30	-.82	-.83	.36	.52
MXL_10_pst	-.32	.32	.05	-.45	-.44	.32	.50
MXL_5_pst	-.29	.34	.11	-.32	-.29	.36	.42
Annual streamflow-summary statistics; flow based; n = 30							
Q_bnkfl	0.15	-0.21	0.34	0.19	0.14	-0.22	-0.16
Q_max	-.10	.12	.21	-.11	-.13	.23	.22
Q_10	-.19	.08	.39	-.19	-.24	.27	.39
Q_50	.09	.11	.48	.08	.04	.30	.31
Q_90	.09	.19	.39	.07	.03	.27	.34
Q_bnkflDA	.42	-.31	.19	.42	.40	-.39	-.45
Qmax_instDA	.45	-.33	.00	.48	.46	-.44	-.54
Q_50DA	.49	-.05	.46	.46	.44	.01	-.10

[1] GIS variables shown had at least one statistically significant correlation (p ≤ 0.01) when compared to these hydrologic condition metrics.

100-meter buffer	Segment buffer			Forest patches		Wetland patches	
Impervious	Developed low intensity	Developed medium intensity	Developed high intensity	Number of patches	Mean shape index	Mean patch area	Proportion like adjacencies
NLCD_BIS	NLCD_S22	NLCD_S23	NLCD_S24	NP_C4	SIM_C4	PAM_C9	PLA_C9
0.92	0.76	0.70	0.59	-0.32	-0.56	-0.51	-0.57
Pre-ice period (Oct. 1–Dec. 8, 2003) hydrologic-condition metrics, area based; n=22							
0.15	-0.02	-0.09	0.04	-0.30	-0.03	-0.26	-0.19
.06	-.14	-.25	-.16	-.18	-.08	-.16	-.10
.11	-.08	-.19	-.30	.07	-.19	-.15	-.11
.72	.36	.43	.54	-.44	-.43	-.67	-.71
.45	.14	.07	.05	-.44	-.29	-.66	-.58
-.10	.05	-.08	-.05	-.12	-.05	.19	.21
.79	.60	.58	.59	-.26	-.73	-.51	-.54
.79	.42	.38	.40	-.27	-.66	-.71	-.72
.51	.08	.07	.05	-.17	-.21	-.56	-.55
-.67	-.60	-.58	-.43	.46	.58	.68	.69
-.62	-.69	-.82	-.76	.38	.23	.41	.41
.02	.05	.06	.02	.20	.18	.04	.05
.22	.05	.18	.07	-.05	-.23	-.24	-.22
Post-ice period (Mar. 16–Oct. 30, 2004) hydrologic-condition metrics, area based; n=24							
0.20	-0.03	-0.15	-0.01	-0.06	-0.08	-0.11	-0.14
-.08	-.16	-.18	-.18	.29	.02	.10	.13
.47	.19	.16	.30	-.32	-.20	-.35	-.41
-.31	-.05	-.18	-.25	-.09	.09	.19	.21
.88	.55	.54	.62	-.17	-.58	-.48	-.51
-.09	.05	-.04	-.02	-.02	.01	.18	.24
-.19	.09	-.11	-.12	.63	-.07	.52	.51
-.75	-.76	-.76	-.75	.37	.43	.28	.27
-.76	-.68	-.67	-.60	.26	.48	.51	.52
-.40	-.01	-.07	-.15	.30	.26	.52	.52
-.31	.00	-.04	-.10	.40	.24	.42	.43
Annual streamflow-summary statistics; n = 30							
0.17	0.03	-0.09	-0.07	0.06	-0.16	-0.28	-0.29
-.15	-.20	-.24	-.18	.61	.13	.12	.12
-.26	-.39	-.34	-.22	.74	.16	.33	.30
.08	-.04	-.06	.06	.63	.07	.23	.18
.07	-.04	-.02	.18	.48	.06	.26	.22
.40	.34	.14	.02	-.45	-.39	-.54	-.60
.48	.46	.28	.16	-.35	-.41	-.60	-.61
.45	.41	.32	.30	.03	-.24	-.16	-.24



[1] When total fall of cross-sectional area is greater than or equal to 3 times the median total fall over the pre-ice period of record (Oct. 1–Dec. 8, 2003).

[2] When total rise of cross-sectional area is greater than or equal to 3 times the median total rise over the pre-ice period of record (Oct. 1–Dec. 8, 2003).

Figure 21. Relations between wetland, forest, and development-fragmentation metrics and hydrologic metrics for the Milwaukee to Green Bay, Wis., study area.

None of the GIS variables were associated with base flow at $p<0.001$, an indication that a deterministic effort such as groundwater modeling may be required. Modeling takes into account sub-surface transmissivity, confining layers, and topography to represent base flow accurately. Nonetheless, a moderate positive ($p<0.01$) correlation was observed between the proximity of water patches (PIM_C1) and the number of forest patches (NP_C4) with increasing base flow (fig. 21*F*). There was an especially strong association for the moderately/least urbanized sites (20<UII<40) between the number of forest patches and base flow; a three- fold increase in forest patches was associated with more than a six-fold increase in base flow (fig. 21*F*).

In summary, it may require a deterministic modeling effort (groundwater and surface water) to fully characterize hydrologic change associated with urbanization (Krohelski and others, 2000; Hunt and others, 2001; Steuer and Hunt, 2001). There were, however, numerous land covers for which the fragmentation or patch variable (management oriented) showed more significance than the overall watershed land cover. These GIS land-cover variables may provide substantial insight into the hydrologic-condition metric change associated with urbanization and are worth deeper investigation.

Habitat characteristics correlated with a few area-based hydrologic characteristics and annual streamflow-summary statistics (table 10). As expected, bankfull-channel dimensions and length of bank erosion positively correlated to increases in post-ice frequent high flow (periodr9); as described earlier, some of the highest correlations were with the hydrologic-condition metric and urban indicators. Another post-ice metric for median duration of high flow (MDH_95) also positively correlated with urban indicators and with bankfull-channel dimensions. The post-ice Richards-Baker flashiness index (rb_flash), however, did not correlate with bankfull-channel dimensions. Shallow bankfull channels and more bank vegetation were present in sites with high maximum duration of high flow events (MXH_95) during the pre-ice period. A high percentage of pools were present in sites with a high frequency of small hydrograph rises (periodr1) during the post-ice period. Streambed substrate conditions correlated with bankfull discharge (Q_bnkfl) and unit-area bankfull discharge (Q_bnkflDA); larger streambed particle sizes and less embeddedness were found in sites with high unit-area bankfull flow than in sites with small unit-area bankfull flows. As stated earlier, annual median flow normalized by drainage area (Q_50DA) increased with increasing urbanization; however, it did not correlate with bankfull-channel dimensions or length of bank erosion.

Water Chemistry

Urbanization may increase the amount of and variety of pollutants entering waterways. The USEPA National Water Quality Inventory 2000 Report to Congress identified urban runoff as one of the leading sources of water-quality impairment in surface waters (U.S. Environmental Protection Agency, 2002a). Previous USGS NAWQA studies have documented increases in concentrations of chlorides and other ions, certain organic contaminants, and trace metals with increasing urbanization (Coles and others, 2004; Harris and others, 2005). Of the 11 pollution-source categories listed in the USEPA report, “urban runoff/storm sewers” was ranked as the fourth leading source of impairment in rivers, third in lakes, and second in estuaries (U.S. Environmental Protection Agency, 2005). These pollutants can include sediment; chloride from road salts; fertilizers and pesticides used on lawns; oils, greases, and petroleum by-products from automobiles; heavy metals from roofing shingles and automobiles; and fecal bacteria and viruses from pets, and septic-, and sanitary-sewer systems. Natural land cover allows for more infiltration of rainfall than do impervious surfaces. Runoff in areas with 100-percent natural land cover is about 10 percent of the total rainfall; while in areas with 75 percent impervious surface, runoff can be as high as 55 percent (U.S. Environmental Protection Agency, 2003).

High-Intensity Samples—Seasonality

Six samples were collected at each of the 10 high-intensity sites during 2003 and 2004 in a variety of seasonal and flow conditions. The six samples were collected through the year, and at least one sample was collected in each season. For purposes of analyzing for seasonal response, the samples collected were given seasonal classifications of one of the following: fall; winter; early spring; late spring; early summer; or late summer.

A significant statistical difference in seasonal concentrations for one field parameter—dissolved oxygen ($p=0.002$) was noted. Higher dissolved oxygen concentrations during the cold seasons are expected as the solubility of oxygen increases with cold temperatures. Specific conductance (SC) values at the high-intensity sites were generally higher during the winter. A seasonal response only was observed at sites with higher UII scores (fig. 22). SC is an indicator of the presence of dissolved solids that include calcium, chloride, sodium, and magnesium. Higher SC readings would be expected during the winter in Wisconsin. Winter is associated with the use of salts as deicers on roads and parking lots. The Wisconsin Department of Transportation typically applies 100 to 300 pounds of road salt per mile on public roads (Wisconsin Department of Transportation, 1996).

Table 10. Spearman rank correlations between the reduced habitat and hydrologic variables with a Spearman's rho value greater than 0.58 ($p \leq 0.001$) for 30 sites in the Milwaukee to Green Bay, Wis., study area.

[Pre-ice (October 1 to December 8, 2003) hydrologic condition metrics are area-based; n=22; for $p \leq 0.001$, rho = 0.667 (dark green); for $p \leq 0.01$, rho = 0.544 (green); for $p \leq 0.05$, rho = 0.423 (light green). Post-ice (March 16 to October 30, 2004) hydrologic condition metrics are area-based; n=24; $p \leq 0.001$, rho = 0.642 (dark green); for $p \leq 0.01$, rho = 0.521 (green); for $p \leq 0.05$, rho = 0.404 (light green). Annual streamflow-summary statistics are flow-based; n = 30; for $p \leq 0.001$, rho = 0.580 (dark green); for $p \leq 0.01$, rho = 0.467 (green); for $p \leq 0.05$, rho = 0.362 (light green); with Bonferroni adjustments for multiple tests (53), the critical rho is 0.66 for a p-value of 0.05. Correlations greater than the Bonferroni adjustment are in **bold.** Metric definitions are listed in appendixes 1-4 and 1-5; metric suffiixes "pre" and "pst" refer to pre-ice and post-ice periods, respectively.]

Habitat characteristic abbreviation	Hydrologic-condition metrics						Annual streamflow-summary statistics			
	mxh_95_pre	rb_flash_pst	mxh_95_pst	mdh_95_pst	periodr1_pst	periodr9_pst	Q_bnkfl	Q_max	Q_bnkflDA	Q_50DA
BFWidthNoPools	0.15	0.02	0.12	-0.22	-0.16	0.32	0.62	0.44	0.17	0.32
BFWidthDA	-.46	.22	-.40	-.47	.30	.37	.02	-.39	.58	.41
BFDepthNoPools	-.14	-.10	-.12	-.25	-.36	.35	.47	.01	.27	.23
BFDepthDA	-.58	.06	-.49	-.48	.19	.34	-.14	-.63	.50	.24
BFAreaNoPools	.10	-.03	.04	-.25	-.26	.39	**.68**	.28	.26	.36
BFAreaNoPoolsDA	-.44	.18	-.34	-.51	.04	.51	.32	-.25	.65	.43
BFWidthDepthNoPools	.23	.10	.17	-.13	.16	.17	.43	.44	.10	.21
GCUTypeRiffPct	-.08	-.02	.04	-.29	.23	.09	.46	.05	.38	.13
GCUTypePoolPct	.04	-.07	.12	.18	.60	-.12	-.07	-.06	-.19	-.19
GCUTypeRunPct	.00	-.06	-.13	-.01	-.53	.05	-.14	-.07	-.03	.06
DepthAvg	-.09	-.31	-.14	-.30	-.12	.28	.16	-.02	.04	.30
RchVol	.16	-.27	.06	-.31	-.21	.31	.35	.15	.06	.42
RchVolDA	-.22	-.08	-.29	-.51	.06	.41	.14	-.26	.38	.46
WidthDepthAvg	.22	.25	.26	-.05	.14	.08	.40	.36	.19	.17
ChStab	-.12	.50	.02	.14	.09	.02	.11	.05	.23	-.21
VelocAvg	-.21	.07	-.06	-.20	.25	.22	.46	.04	.31	.28
FinesPct	.14	.01	.16	.14	-.23	.00	**-.70**	.02	-.54	-.27
SiltCovPct	-.01	-.07	-.13	-.15	-.24	-.01	-.34	-.08	-.27	-.30
BedSubIndex	.18	-.32	-.05	.01	.25	-.27	.57	-.21	.49	.20
EmbedPctAvg	.01	.17	-.04	.16	-.34	.09	-.58	.11	-.59	-.32
BankVegCov	.52	-.11	-.14	.26	-.17	-.36	.17	-.24	.01	-.10
ErosionLengthAvg	-.45	.32	.23	-.38	-.18	.63	-.02	.30	-.11	.16

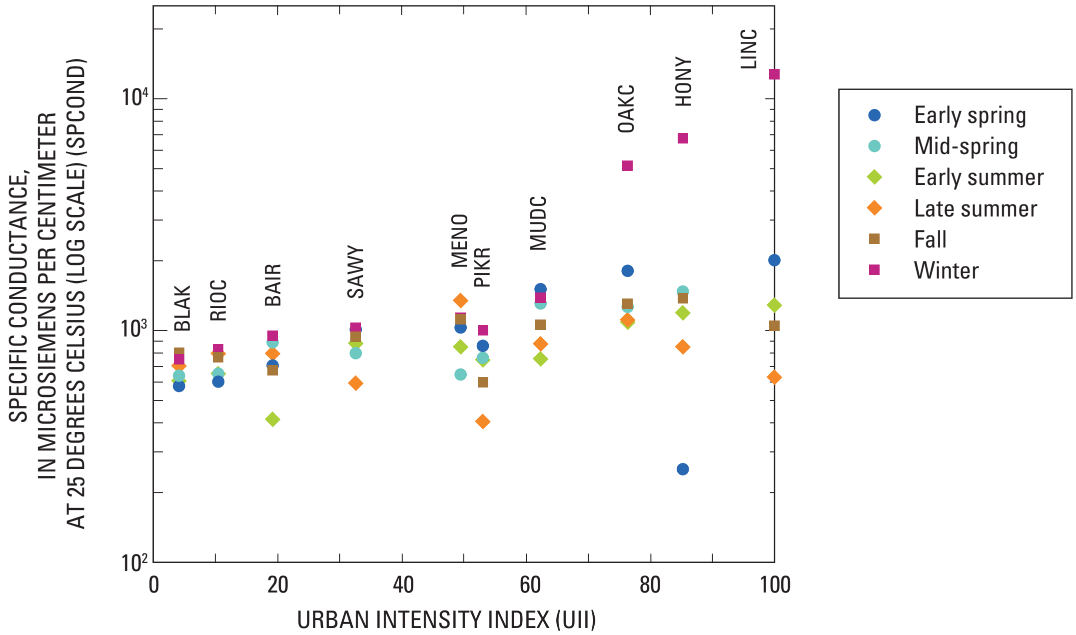


Figure 22. Relation between seasonal specific conductance values and urban intensity index for 10 study sites in the Milwaukee to Green Bay, Wis., study area.

Seasonal variability in chloride concentrations was obvious only when plotted against the UII with a score above 50. Chloride concentrations were greater and more variable at sites where watershed impervious surface (NLCD_IS) was greater than 10 percent (fig. 23). The higher concentrations (ranging from 32 to >4,000 mg/L) and increased variability at sites with higher percentages of impervious surface (above 10 percent) is expected because chloride is used extensively as a deicer on roads and parking lots in Wisconsin. Typical chloride concentrations in unpolluted surface waters (river and spring) range from 0 to 25 mg/L (Hanes and others, 1970). A high concentration (>4,000 mg/L) of chloride was observed in samples collected in the Milwaukee area following a light snowfall (less than 2 in.). Because of the small amount of snow, resulting runoff contained high concentrations of chloride that entered the streams. This small amount of highly enriched runoff entered the streams during base-flow conditions, resulting in high chloride concentrations in the streams. The high-intensity sites with the highest percentage of impervious surfaces—Lincoln Creek (45 percent), Honey Creek (48 percent), and Oak Creek (27 percet) produced a chloride concentration above the Wisconsin Department of Natural resources (WDNR) Chronic Toxicity Level of 395 mg/L (Wisconsin Department of Natural Resources, 1998; United States Environmental Protection Agency, 2006b). A chloride concentration for the Oak Creek and Lincoln Creek samples was above the WDNR Acute Toxicity Level of 757 mg/L (1,480 and 4,040 mg/L, respectively) (Wisconsin Department of Natural Resources, 1998; United States Environmental Protection Agency, 2006b).

More than two-thirds of the atmospheric sulfate in northern industrialized areas is from human input in origin. Sulfate concentrations showed a significant statistical difference between seasons ($p=0.0008$), with the highest concentrations during cold weather (winter and early spring). Human input into the atmosphere is in the form of sulfur gases from burning of fossil fuels. These sulfur gases usually oxidize to form sulfate when they enter the atmosphere. In northern industrial areas, fossil fuel-burning is greater in the winter and thus seasonal fluctuations can be expected (Arizona Board of Regents, 2005).

Phosphorus, one of the most common elements on earth, is an essential nutrient for all plant and animal life and is used extensively as inorganic fertilizer in agriculture and urban areas. Total phosphorus was the only nutrient analyte with a significant statistical difference ($p=0.025$) in seasonal concentrations. Median total phosphorus concentrations were greater in samples from mid-spring through summer when phosphorus fertilizers are applied in both agriculture and urban areas.

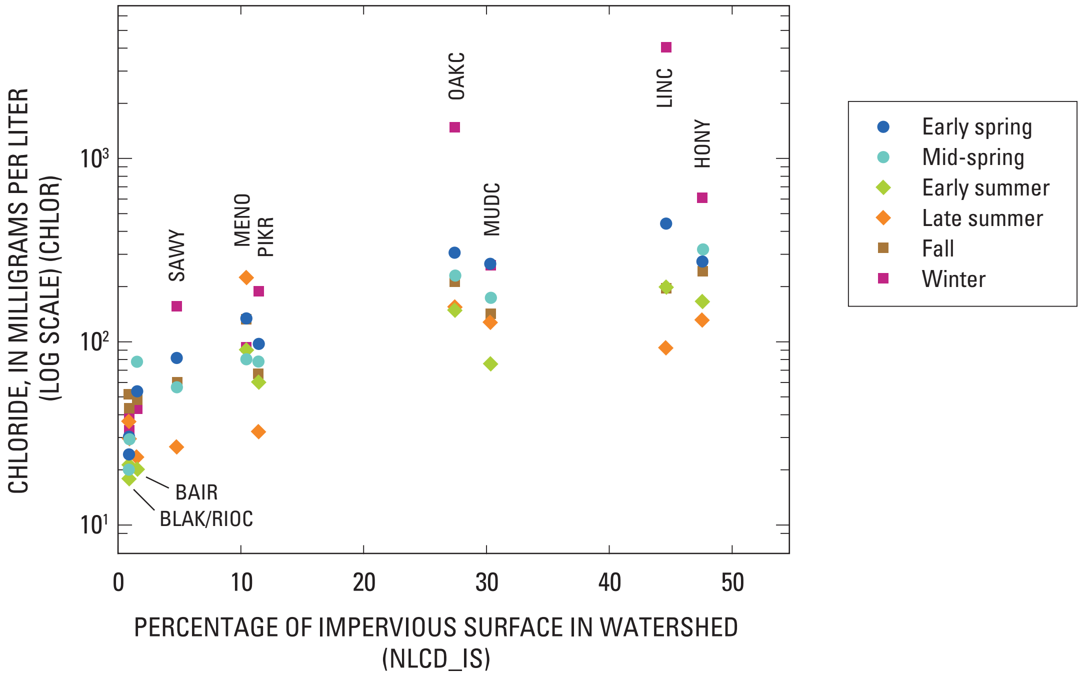


Figure 23. Relation between seasonal chloride concentrations and percentage of impervious surface in the watershed for 10 study sites in the Milwaukee to Green Bay, Wis., study area.

In agriculture areas, pesticides either are incorporated with the seed or applied soon after emergence. In urban areas in the study area pesticides typically are applied the first time in mid- to late spring. The maximum concentrations in streams normally occur during the first major runoff after application and can vary, depending on the type of application. Total pesticide concentrations were statistically different ($p=0.001$) between seasons, with the highest median concentrations in the mid-spring and early summer samples (fig. 24). The variability of total pesticide concentrations is associated with the applications of these chemicals. Total pesticide concentrations at the high-intensity sites increased with agriculture land cover in the watershed and not with an increase in urbanization. The site with the highest single concentration of a pesticide was the Pike River (UII of 53); 48 percent of the land cover in the Pike River watershed was in cultivated crops.

Low-Intensity Samples—Spring 2004

The spring water-chemistry samples were collected when the flows were high (between Q50 and Q10) (fig. 25) (table 11). In the spring sample, the chemical variables with the strongest correlations to the UII were chloride (rho=0.78), dissolved organic carbon (rho=-0.71), specific conductance (rho=0.69), diazinon (rho=0.67), and prometon (rho=0.66).

Chloride showed the most and the strongest correlations to variables related to urbanization (23), particularly to the percentage of impervious surface in the watershed (NLCD_IS) (rho = 0.86) (fig. 26*A*). Chloride showed a number of positive correlations to variables related to roads, urban land cover, and urban-land distribution variables (fragmentation or fragstat); these include the proportion/percentage of patch adjacencies that are developed (urban) (PLA_C2) (rho = 84). Chloride concentrations for the spring sample increased as the urban landscape variables in the watershed increased. The increasing chloride concentrations were similar to other studies that have been conducted in areas where road salts are used to de-ice roads and parking lots. Researchers at the Institute of Ecosystem Studies in Millbrook, N.Y., studied three locations in Baltimore County, the Hudson River Valley, and the White Mountains in New Hampshire. Researchers concluded that freshwater salinity has been increasing over the past 30 years. In the Baltimore area, there was a strong association between impervious surface coverage (roads and parking lots) and chloride concentration (Institute of Ecosytem Studies, 2006). Chloride was strongly correlated with infrastructure variables such as road density (ROADDEN; rho= 79) and road traffic density (RDTRDEN; rho = 82). The USEPA Master List of Compounds Emitted by Mobile Sources reported a maximum emission rate of chloride (in several forms) in vehicle exhaust to be 30.3 mg/mi (U.S. Environmental Protection Agency, 2006a).

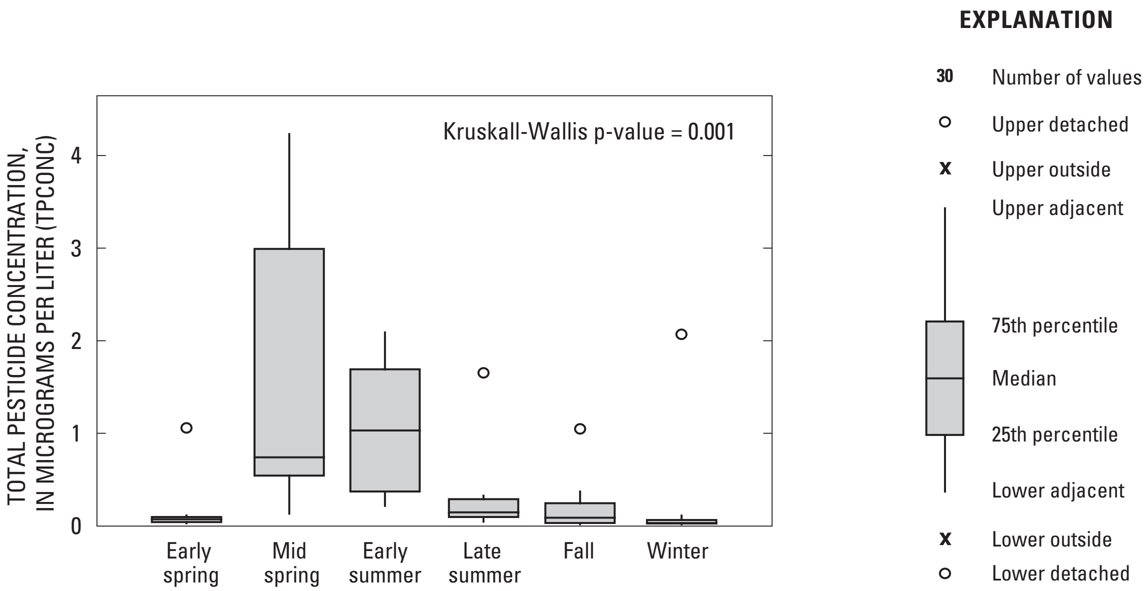


Figure 24. Total pesticide concentration by season for 10 study sites in the Milwaukee to Green Bay, Wis., study area.

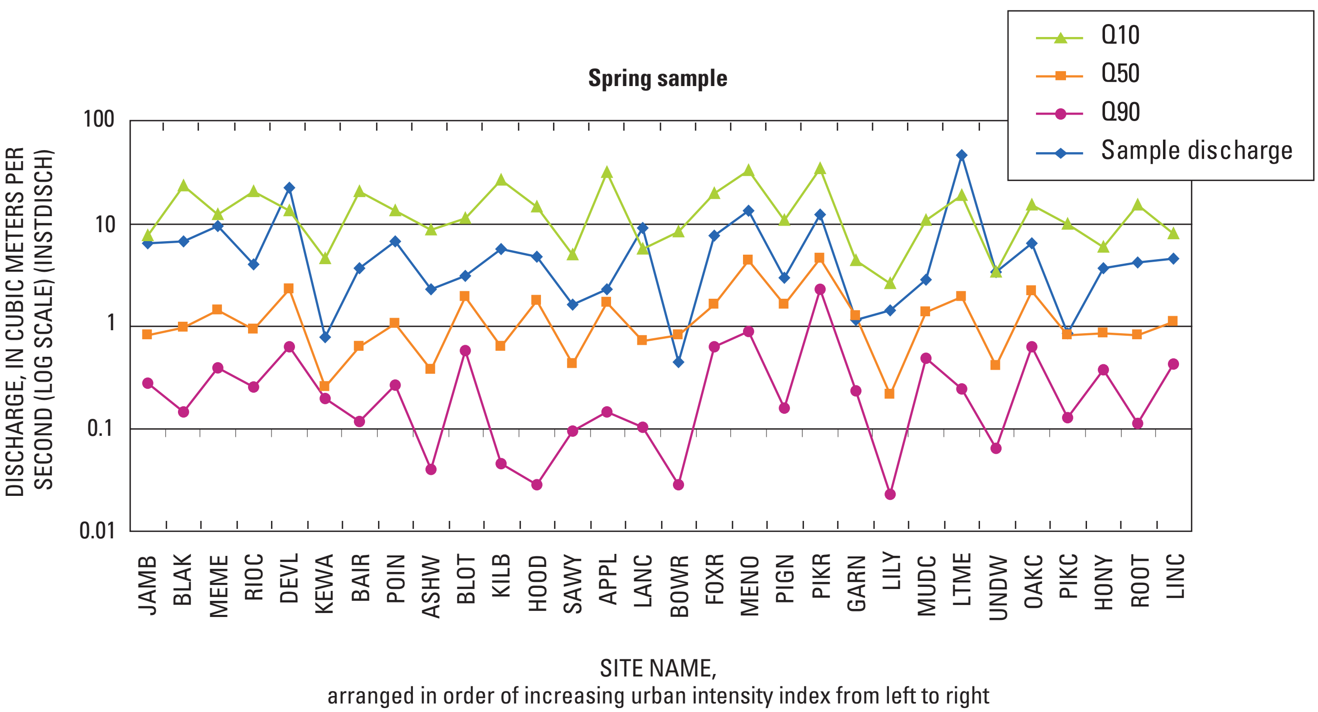


Figure 25. Sample discharge for the spring sample, Q10 (discharge that is exceeded 10 percent of the time), Q50 (discharge that is exceeded 50 percent of the time), and Q90 (discharge that is exceeded 90 percent of the time) at 30 study sites in the Milwaukee to Green Bay, Wis., study area.

Table 11. Spearman rank correlations between the reduced spring water-quality characteristics and geographic information system (GIS) characteristics for 30 sites in the Milwaukee to Green Bay, Wis., study area.

[For individual correlations, the critical rho value for 30 sites is 0.47 for a p-value of 0.01 and 0.58 for a p-value of 0.001; with Bonferroni adjustments for multiple tests (53), the critical rho is 0.68 for a p-value of 0.05. Correlations greater than the Bonferroni adjustment are in **bold**, correlations where a distinct pattern was not found are in **bold red** text; dark green indicates p ≤ 0.001; green indicates p ≤ 0.01; light green indicates p ≤ 0.05. Characteristic definitions are listed in appendixes 1-2 and 1-6.]

GIS characteristic abbreviation	Specific conductance	Chloride	Sulfate	Dissolved organic carbon	Total phosphorus	Ortho-phosphorus	2-Chloro-4-isopropylamino-6-amino-s-triazine	Atrazine	Diazinon	Metolachlor	Prometon	Simazine
	SPCOND	CHLOR	SULFA	DISORGC	TOTALP	ORTHOP	CHLIS	ATRAZ	DIAZI	METOL	PROME	SIMAZ
UII	**0.69**	**0.78**	0.56	**-0.71**	-0.59	-0.57	-0.26	-0.30	0.67	-0.50	0.66	-0.48
ROADDEN	**.69**	**.79**	.54	-.67	-.60	-.58	-.34	-.38	.61	-.56	.64	-.53
RDARDEN	**.70**	**.78**	.54	**-.68**	-.56	-.53	-.35	-.38	.61	-.55	.64	-.52
RDTRDEN	**.75**	**.82**	.58	**-.68**	-.53	-.47	-.31	-.34	.59	-.53	.64	-.52
NLCD.BIS	**.75**	**.81**	.61	**-.72**	-.61	-.51	-.16	-.18	.58	-.38	**.71**	-.57
P_NLCD1_B2	**.69**	**.76**	.55	**-.73**	-.64	-.55	-.31	-.35	.59	-.51	**.69**	-.63
NLCD.IS	**.77**	**.86**	.64	**-.73**	-.58	-.49	-.17	-.19	**.61**	-.42	**.71**	-.50
P_NLCD1_2	**.76**	**.84**	.64	**-.70**	-.58	-.51	-.22	-.26	.60	-.48	**.68**	-.50
P_NLCD1_8	-.54	-.65	-.37	.44	.62	.67	.58	.63	**-.60**	**.72**	-.66	.56
PNLCD 21	.65	**.75**	.56	-.56	-.59	-.61	-.36	-.41	.58	-.58	**.63**	-.52
PNLCD 22	**.72**	**.79**	.60	**-.70**	-.54	-.48	-.25	-.31	.57	-.50	**.71**	-.51
PNLCD 23	**.77**	**.86**	.65	**-.76**	-.61	-.52	-.16	-.14	**.62**	-.38	**.71**	-.49
PNLCD 24	**.72**	**.81**	.61	-.67	-.51	-.47	-.11	-.14	.58	-.35	**.73**	-.42
PNLCD82	-.45	-.53	-.25	.30	.58	.61	.58	.65	-.45	**.72**	-.47	**.63**
LPI.C2	**.74**	**.81**	.58	**-.71**	-.60	-.51	-.25	-.28	.59	-.47	**.71**	-.53
PAM.C2	**.73**	**.80**	.58	**-.71**	-.57	-.49	-.24	-.28	.58	-.46	**.72**	-.50
PLA.C2	**.76**	**.84**	.65	**-.72**	-.62	-.52	-.21	-.24	.61	-.45	**.68**	-.51

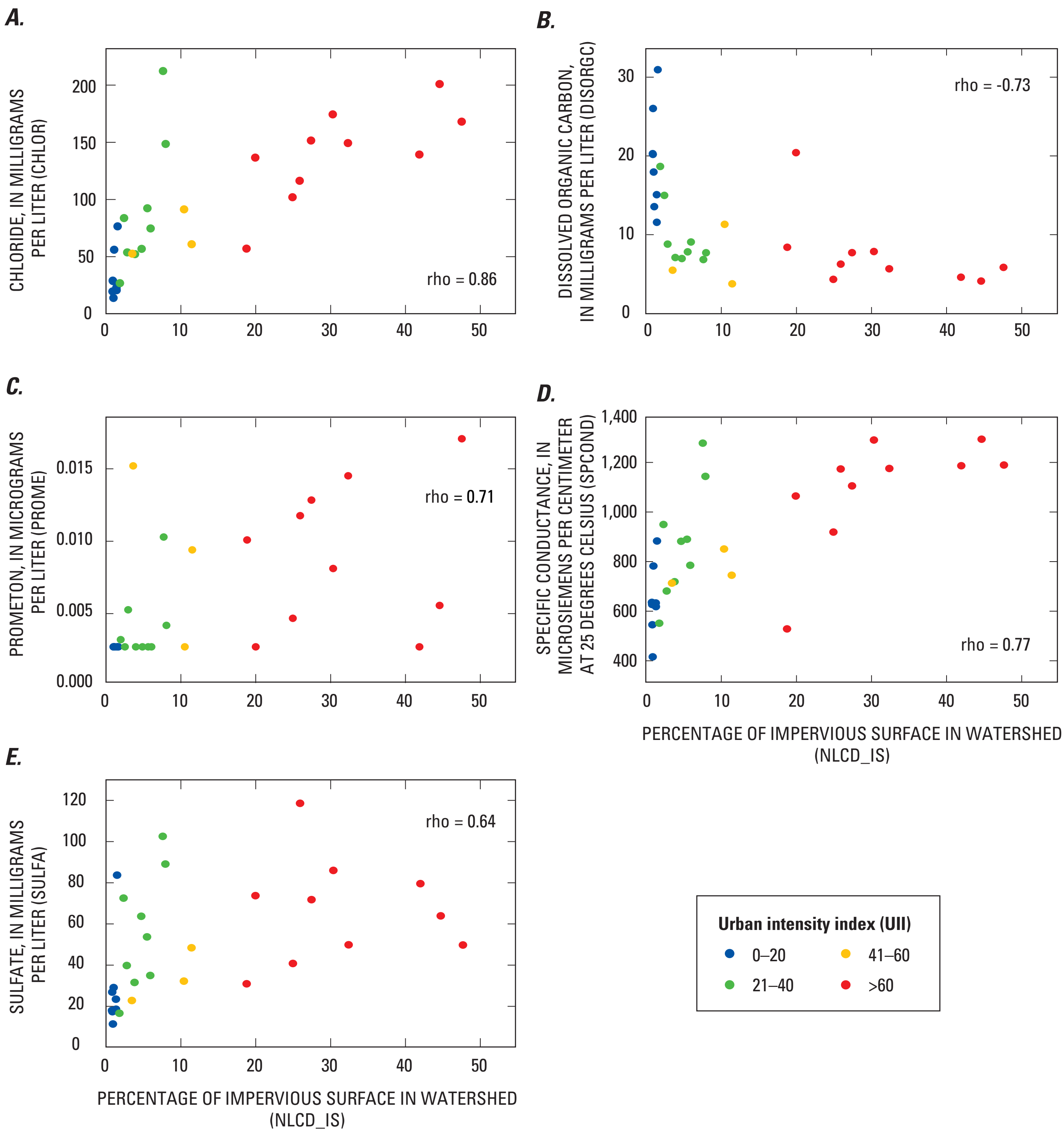


Figure 26. Relations between chloride, dissolved organic carbon, sulfate, prometon, and diazinon and percentage of impervious surface in the watershed in the spring 2004 sample for 30 study sites in the Milwaukee to Green Bay, Wis., study area.

Combustion of fossil fuels releases sulfur to the atmosphere and accounts for a majority of the human source of sulfur oxides. To a lesser extent than chloride, sulfate showed a number of positive correlations to variables related to roads, percentage of impervious surface in the watershed (NLCD_IS) (rho = 64 (fig. 26*E*), and medium-density urban land cover (PNLCD_23) (rho = 65). Sulfur in the atmosphere is oxidized into sulfate and returns to the surface through rainfall or dry deposition.

Dissolved organic carbon enters streams through precipitation, leaching, and decomposition of organic matter that occurs more readily in areas with less impervious surfaces. Dissolved organic carbon showed a strong negative correlation with the percentage of impervious surface (NLCD.IS) (rho = -0.73) (fig. 26*B*) and developed land in the watershed (P_NLCD1_2) (rho = -0.70).

The USGS NAWQA Program, in summarizing findings from data collected by the Study Units, found elevated concentrations of nitrate and phosphorus downstream from agriculture and urban areas (U.S. Geological Survey, 1999). No positive correlations were found between any of the nutrient analytes and urban landscape variable. Total and ortho-phosphorus positively correlated to a few landscape variables related to agriculture, including land cover (P_NLCD1_8) (table 11). The major human source of nitrogen and phosphorus in the environment is the use of fertilizers in rural and urban areas. One possible reason that neither ammonia nor ortho-phosphorus correlated with urban land cover for this study was the lack of wastewater-treatment plants upstream from any of the urban sites. The USEPA, in its ecoregion-based nutrient criteria, addressed cultural eutrophication (the adverse effects of excess human nutrient inputs), where criteria were empirically derived to represent surface waters that are minimally affected by human activities and are protective of aquatic life and recreational uses (U.S. Environmental Protection Agency, 2000). The study area lies within Nutrient Ecoregion VII. The recommended USEPA Criteria for Ecoregion VII for total nitrogen is 0.54 mg/L and 0.03 mg/L for total phosphorus. Every sample for total phosphorus and 23 of 30 samples for total nitrogen exceeded the USEPA recommended ecoregion-based nutrient criteria (U.S. Environmental Protection Agency, 2000). The sample at the Kilbourn Ditch (10.69 mg/L) exceeded the USEPA National Water Quality Criteria for nitrate plus nitrite (10 mg/L) (U.S. Environmental Protection Agency, 1986). A majority of land cover (64 percent) in the Kilbourn Ditch drainage watershed is in cultivated crops (PNLCD_82).

Five herbicides commonly used in urban areas (including simazine and prometon) and three commonly used insecticides (including diazinon and carbaryl) were most frequently detected in urban streams throughout the Nation; detections were often at higher concentrations than at agriculture streams (Gilliom and others, 2006). Eight pesticides were detected in at least 10 of the 30 (10/30) samples in this study: 2-Chloro-4-isopropylamino-6-amino-s-triazine (atrazine degradate) (30/30), atrazine (30/30), metolachlor (30/30), prometon (23/30), acetochlor (22/30), simazine (20/30), diazinon (12/30), and carbaryl (11/30). Two of the pesticides detected, prometon (herbicide) and diazinon (insecticide) showed a number of positive correlations related to urban variables such as percentage of impervious surface (NLCD_IS) and urban land cover (P_NLCD1_2) in the watershed and 100-m riparian zone (NLCD_BIS and P_NLCD1_B2), and census variables such as population (POPDEN) and housing (HHDEN) density. Prometon (rho = 0.71) (table 11) showed a strong correlation to percentage of impervious surface of the watershed (fig. 26*C*); the correlation for diazinon (rho = 0.61) (table 11) was less. Prometon is a non-selective herbicide and commonly used for long-term weed control for roadside maintenance and for total weed control around parking lots and industrial buildings (Capel and others, 1999; U.S. Geological Survey, 1999). Diazinon is a non-systemic organophosphate insecticide formerly used to control cockroaches and other insects in homes; it is used on residential gardens and farms to control a wide variety of sucking and leaf-eating insects. Diazinon was the latest organophosphate insecticide to be phased out by the USEPA; it could only be sold for home, lawn and garden use until December 31, 2004 (U.S. Environmental Protection Agency, 2007). Neither acetochlor nor carbaryl correlated with any landscape variables. The remaining herbicides and total-herbicide concentrations positively correlated with variables related to agricultural land-use. Metolachlor showed the strongest correlations of these pesticides to landscape variables, especially to percentage of cultivated crops in the watershed (PNLCD_82) (rho = 0.72) (table 11). A summary of NAWQA pesticide data (1992 to 2001) found herbicides (including atrazine, metolachlor, and acetochlor) most frequently detected in agriculture areas (Gilliom and others, 2006). The most commonly used insecticides within the home and garden sector in 2001 were diazinon, cabaryl, and malathion, and the most commonly used insecticides in the commercial/industry/government sector were chlorpyrifos and malathion (Kiely and others, 2004). The most commonly used herbicides within the home and garden sector and commercial/industry/government sector in 2001 were 2, 4-D, glyphosate, and pendimethalin (Kiely and others, 2004). The pesticide analytical schedule used by NAWQA EUSE did not include analysis for 2, 4-D but did include the other most commonly used insecticides and herbicides. Atrazine, metolachlor, and acetochlor are selective herbicides used to control broadleaf and grassy weeds in agricultural crops. Atrazine was applied to 58 percent, metolachlor and s-metolachlor to 33 percent and acetochlor to 22 percent of the corn crop in 2003 (National Agriculture Statistics Service, 2007a). Atrazine has restrictions on its use in Wisconsin; certain areas of the State cannot use atrazine pesticides (1.2 million acres). The rest of the State must follow guidelines on maximum-use rates, certification of applicators, and timing of applications; atrazine can be used only on agricultural row crops and forest lands (Wisconsin Department of Agriculture, Trade and Consumer Protection, 2007). Two sites exceeded the USEPA National Water Quality Criteria for atrazine (3.0 µg/L) (U.S. Environmental Protection Agency, 1986), Kilbourn Ditch (3.59 µg/L) and Ashwaubenon Creek (7.09 µg/L). A large percentage of Ashwaubenon Creek (50 percent) and the Kilbourn Ditch (64 percent) drainage watersheds are in cultivated crops.

Low-Intensity Samples—Summer 2004

Streamflow conditions were at or near base-flow (Q90) conditions during summer sample collection (fig. 27; table 12). There were fewer correlations between chemical and landscape variables in the summer dataset than there were in the spring dataset. Chloride was the only chemical variable with a significant correlation with the UII (table 12). Similar to the spring sample, the most chloride correlations with landscape variables were related to urbanization (15). Chloride strongly correlated with impervious surface (NLCD_IS) (rho=71), urban land cover (P_NLCD1_2) (rho=71), road traffic density (RDTRDEN) (rho=73), and land distribution (fragstat) variables related to urban land cover; it especially correlated to the percentage of the watershed area composed of the largest developed patch (LPI_C2) (rho=72). Chloride was the only chemical variable with a significant correlation to percentage of impervious surface in the watershed (NLCD_IS) (rho=71) (fig. 28).

There were no significant correlations between any nutrient variable, sulfate, or field parameters (specific conductance, pH, dissolved oxygen, and water temperature) with any urban-landscape variables for the summer samples. Every total phosphorus sample and 18 of 30 samples for total nitrogen exceeded the USEPA-recommended ecoregion-based nutrient criteria (U.S. Environmental Protection Agency, 2000).

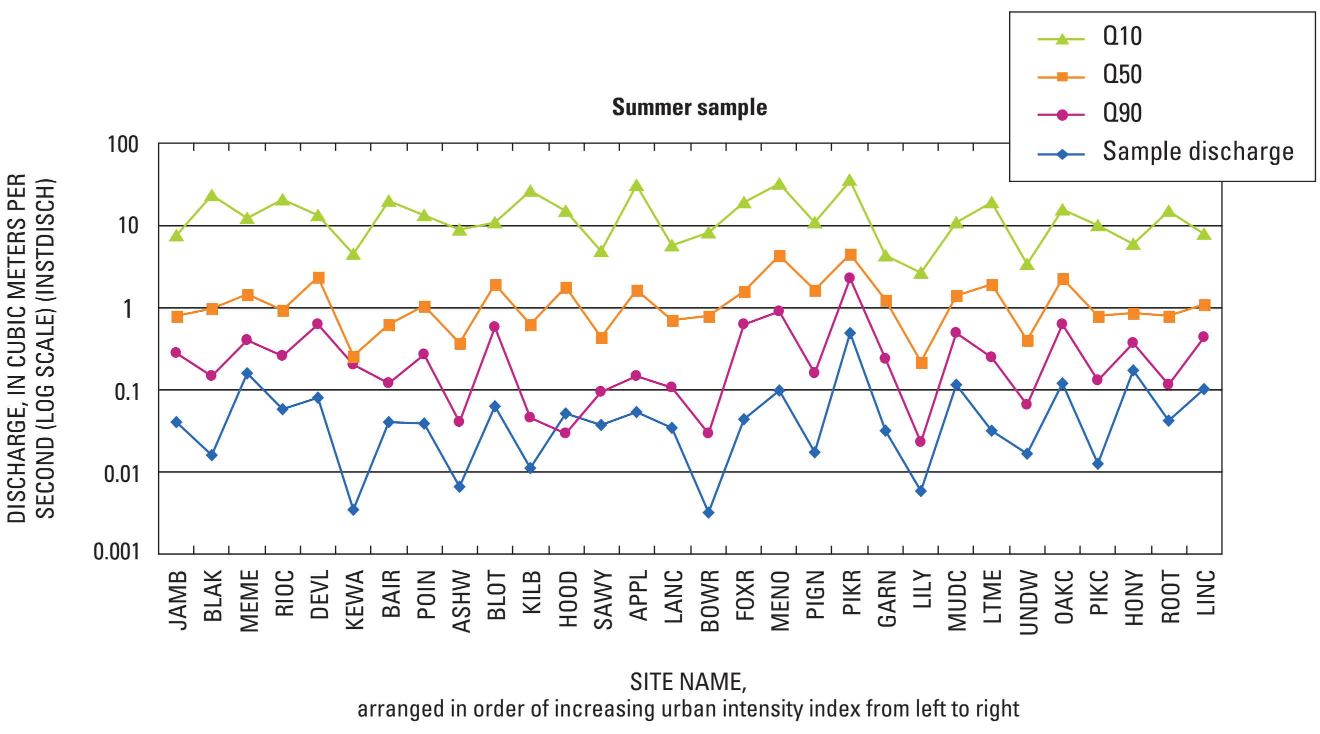


Figure 27. Sample discharge for the summer sample, Q10 (discharge that is exceeded 10 percent of the time), Q50 (discharge that is exceeded 50 percent of the time), and Q90 (discharge that is exceeded 90 percent of the time) at 30 study sites in the Milwaukee to Green Bay, Wis., study area.

Table 12. Spearman rank correlations between summer water-quality characteristics and geographic information system (GIS) characteristics for 30 sites in the Milwaukee to Green Bay, Wis., study area.

[For individual correlations, the critical rho value for 30 sites is 0.47 for a p-value of 0.01 and 0.58 for a p-value of 0.001; with Bonferroni adjustments for multiple tests (53), the critical rho is 0.68 for a p-value of 0.05. Correlations greater than the Bonferroni adjustment are in **bold**; dark green indicates p ≤ 0.001; green indicates p ≤ 0.01; light green indicates p ≤ 0.05. Characteristic definitions are listed in appendixes 1-2 and 1-6.]

GIS characteristic abbreviation	Chloride	2-Chloro-4-isopropylamino-6-amino-s-triazine	Atrazine	Metolachlor	Prometon
	CHLOR	CHLIS	ATRAZ	METOL	PROME
UII	**0.69**	-0.51	-0.37	-0.54	0.44
ROADDEN	**.68**	-.49	-.38	-.56	.47
RDARDEN	**.68**	-.47	-.34	-.52	.51
RDTRDEN	**.73**	-.46	-.30	-.44	.53
RDAREAINDX	.55	-.30	-.37	-.28	.64
RDTRAFINDX	.53	-.28	-.33	-.23	.63
NLCD.BIS	.67	-.44	-.26	-.47	.42
P_NLCD1_B2	.59	-.51	-.37	-.56	.39
P_NLCD1_B8	-.48	.59	.58	**.76**	-.30
NLCD.IS	**.71**	-.48	-.29	-.47	.47
P_NLCD1_2	**.71**	-.50	-.34	-.53	.45
P_NLCD1_8	-.54	.57	.56	**.71**	-.41
PNLCD 21	.58	-.58	-.45	-.67	.36
PNLCD 22	.62	-.54	-.38	-.57	.40
PNLCD 23	.67	-.44	-.22	-.42	.41
PNLCD 24	**.73**	-.44	-.28	-.44	.55
PNLCD82	-.42	**.68**	**.68**	**.80**	-.28
pwNLCD01.24	**.74**	-.38	-.26	-.44	.54
LPI.C2	**.72**	-.45	-.32	-.51	.47
PAM.C2	**.71**	-.49	-.35	-.53	.46
PLA.C2	**.68**	-.50	-.32	-.52	.42

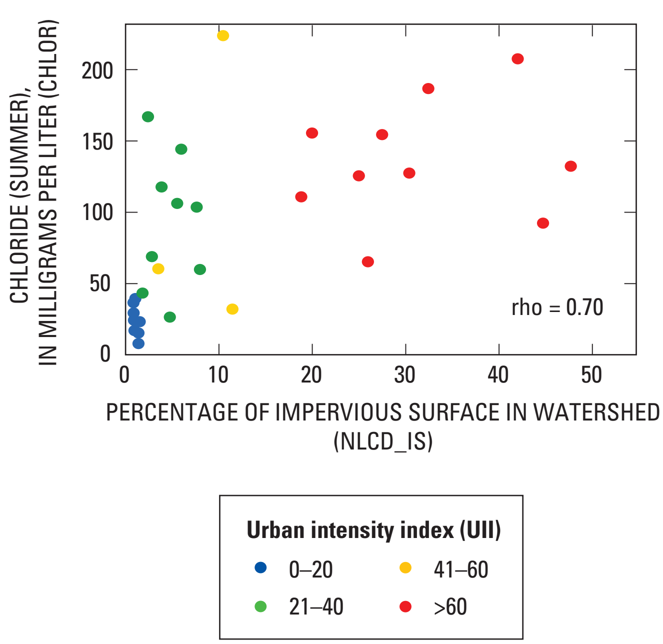


Figure 28. Relation between the summer chloride concentrations and percentage of impervious surface in the watershed for 30 sites in the Milwaukee to Green Bay, Wis., study area.

Four herbicides were detected at 10 or more sites: atrazine (29 of 30), 2-Chloro-4-isopropylamino-6-amino-s-triazine (24 of 30), metolachlor (20 of 30), and prometon (17 of 29). As expected, agriculture herbicides correlated to agriculture-landscape variables and urban herbicides correlated to urban-landscape variables. One site, Black Creek, with a high percentage (68 percent) of agricultural land cover (P_NLCD1_8) showed concentrations of chlorpyrifos above the USEPA chronic and acute criteria for freshwater aquatic invertebrates. The USEPA recommended ambient water quality criterion is a description of the amount of a pollutant or other measurable substance in water that, when met, will protect aquatic life (U.S. Environmental Protection Agency, 2006b). Also, concentrations of malathion in the same sample were greater than the chronic criteria for freshwater aquatic invertebrates (U.S. Environmental Protection Agency, 2006b). Concentrations of both of these compounds were an order of magnitude above any other detection for these insecticides. Chlorpyrifos is a broad-spectrum organophosphate insecticide used in controlling cutworms, corn rootworms, cockroaches, grubs, flea beetles, flies, termites, fire ants, and lice. It is used as an insecticide on grain, cotton, field, fruit, nut, and vegetable crops, as well as on lawns and ornamental plants. It is also registered for direct use on sheep and turkeys, for horse-site treatment, dog kennels, domestic dwellings, farm buildings, storage bins, and commercial establishments (Extension Toxicology Network, 1996a). Chlorpyrifos is used as an insecticide for row crops; in 2002, it was applied to 5 percent of the corn crop in Wisconsin (National Agriculture Statistics Service, 2007b). Malathion is an organophosphate insecticide used in a variety of ways—insect control on fruit and vegetable crops; on commodities such as Christmas trees and agricultural premises; residential uses on lawns, gardens, and commercial horticultural crops (ornamental trees, shrubs, and plants); and for public-health mosquito control and control of gypsy moths. Malathion also may be found in formulation with other pesticides (Extension Toxicology Network, 1996b). Because of the variety of uses for malathion, Wisconsin and county-level application data are not available.

Correlations Between Spring and Summer Samples

Several constituents showed significant correlations to landscape variables for both spring and summer samples. Chloride was the only chemical variable with significant correlations to the UII for spring and summer samples (rho = 0.78 and 0.69), respectively (table 13). Chloride showed numerous overlapping correlations with urban-related landscape variables including impervious surface in the watershed (NLCD_IS), road area (RDARDEN), traffic (RDTRDEN), and density (ROADDEN); urban land in the riparian zone (P_NLCD1_B2) and urban land cover in the watershed (P_NLCD1_2); urban-related census variables (including HUDEN); sampling distance from urban development (pwsumURBAN); and increase in number and size of patches of developed land (including LPI_C2) (table 13). Atrazine, metolachlor, and the atrazine degradate 2-Chloro-4-isopropylamino-6-amino-s-triazine showed overlapping correlations with landscape variables related to agricultural land cover (riparian, watershed, and weighted distance) (table 13). Concentrations of these chemicals increased as the percentage of cultivated land in the watershed increased. The overlapping of correlations for chloride and these pesticides would indicate that the responses are strongly related to the associated land-cover and infrastructure variables and are not overshadowed by the large hydrologic variability between sample sets.

Semipermeable Membrane Devices

PAHs are a group of chemicals that are formed during the incomplete burning of coal, oil, gas, wood, garbage, or other organic substances. PAHs adsorb to particles and are transported to receiving waters through atmospheric deposition, sewage effluent, and surface runoff. Automobile exhaust, lubricating oils, gasoline, tire particles, erosion of street materials, and atmospheric deposition are sources of PAHs in urban runoff (Van Metre and others, 2000). PAH sources are found in greater numbers in urban areas than agriculture areas, and their use does not vary by season. It would be expected that PAHs would have more significant correlations to urban variables than many of the other chemicals sampled. Results of chemical analysis of SPMDs indicate that two measures of potential toxicity and concentrations of four PAHs were strongly correlated with the UII (table 14). Two of the bioassays performed on the SPMD extract, the P450 Reporter Gene Systems (P450RGS) expressed in toxicity equivalents (TEQ) and the ultraviolet fluorescence scan (UPAH), showed strong correlations with the UII. The third assay, measured toxicity through the Microtox EC50 bioassay (EC50), did not correlate with any landscape variables used for data analysis, the other bioassays, or any of the SPMD chemical variables used in the data analysis. The PAH compounds benzo(a)pyrene (found in 12 of 28 samples), fluoranthene (19 of 28), pyrene (19 of 28), and phenanthrene (18 of 28) showed strong correlations with the UII.

Toxicity-potential assays TEQ and UPAH, were strongly correlated with each other and also with the PAH compounds that were detected in a minimum of 10 samples. The UPAH test is based on a pyrene index and is a screening tool for PAHs; the TEQ assay is a screening tool for compounds that include PCBs, PAHs, dioxins, and furans. Strong correlations would be expected between these tests and PAH concentration.

Table 13. Overlapping Spearman rank correlations between analyte and geographic information system characteristics for 30 sites in the Milwaukee to Green Bay, Wis., study area, with a Spearman's rho value greater than 0.58 (p-0.001).

[GIS, geographic information system; NLCD, National Land Cover Database. Correlations greater than the Bonferroni adjusted number 0.68 for a p-value of 0.05 are in **bold**. Characteristic definitions are listed in appendixes 1-2 and 1-6.]

Characteristic type	Spring sample			Summer/ecological sample		
	Analyte	GIS characteristic abbreviation	rho value	Analyte	GIS characteristic abbreviation	rho value
Urban intensity index	Chloride	SU.UII	**0.78**	Chloride	SU.UII	**0.69**
Infrastructure variables	Chloride	RDTRFDEN	**.82**	Chloride	RDTRFDEN	.68
	Chloride	ROADDEN	**.79**	Chloride	ROADDEN	**.70**
	Chloride	RDARDEN	**.78**	Chloride	RDARDEN	**.68**
NLCD 2001 riparian variables	Chloride	NLCD.BIS	**.81**	Chloride	NLCD.BIS	**.68**
	Chloride	PNLCD1B2	**.76**	Chloride	P.NLCD1.B2	.60
	Metolachlor	PNLCD1B8	**.71**	Metolachlor	PNLCD1B8	**.76**
NLCD 2001 land-use variables	Chloride	NLCD.IS	**.86**	Chloride	NLCD.IS	**.70**
	Chloride	P_NLCD1_2	**.84**	Chloride	P_NLCD1_2	**.71**
	Atrazine	P_NLCD1_8	.63	Atrazine	P_NLCD1_8	.59
	2-Chloro-4-isopropylamino-6-amino-s-triazine	P_NLCD1_8	.58	2-Chloro-4-isopropylamino-6-amino-s-triazine	P_NLCD1_8	.58
	Metolachlor	P_NLCD1_8	**.72**	Metolachlor	P_NLCD1_8	**.71**
	Atrazine	PNLCD_82	.65	Atrazine	PNLCD_82	**.68**
	2-Chloro-4-isopropylamino-6-amino-s-triazine	PNLCD_82	.58	2-Chloro-4-isopropylamino-6-amino-s-triazine	PNLCD_82	**.68**
	Metolachlor	PNLCD_82	**.72**	Metolachlor	PNLCD_82	**.80**
2000 Census variables	Chloride	HUDEN	**.84**	Chloride	HUDEN	.66
	Chloride	HHDEN	**.83**	Chloride	HHDEN	.67
	Chloride	POP2000	**.83**	Chloride	POP2000	.65
	Chloride	POPDENKM	**.82**	Chloride	POPDENKM	.66
	Chloride	PPRURAL	**-.79**	Chloride	PPRURAL	-.66
	Chloride	PPURBAN	**.79**	Chloride	PPURBAN	.66
	Chloride	PHU.G60	-.76	Chloride	PHU.G60	-.65
NLCD 2001 distance weighting variables	Atrazine	pwNLCD01.82	.60	Atrazine	pwNLCD01.82	.63
	Chloride	pwsumURBAN	**.80**	Chloride	pwsumURBAN	**.68**
	Chloride	pwsumAGRICULTURE	**-.69**	Chloride	pwsumAGRICULTURE	-.62
	Metolachlor	pwNLCD01.82	.66	Metolachlor	pwNLCD01.82	**.79**
2001 NLCD 2001 segment variables	Chloride	pAGRICULTUREseg	-.60	Chloride	pAGRICULTUREseg	-.62
Fragstat variables	Chloride	PLA.C2	**.85**	Chloride	PLA.2	**.69**
	Chloride	LPI.C2	**.81**	Chloride	LPI.2	**.72**
	Chloride	PAM.C2	**.81**	Chloride	PAM.2	**.71**
	Chloride	LPI.C8	**-.68**	Chloride	LPI.8	**-.71**
	Chloride	PIM.C2	**.68**	Chloride	PIM.2	.65
	Chloride	PIM.C8	-.66	Chloride	PIM.8	-.62

Table 14. Spearman rank correlations between semipermeable membrane device (SPMD) based toxicity potential, chemical, and geographic information system (GIS) urban characteristics for 30 sites in the Milwaukee to Green Bay, Wis., study area.

[CYP1A1, quantification of this gene serves as a measure of dioxin activity; TEQ, toxics equivalents; UPAH, ultraviolet fluorescence. The critical correlation for 28 sites and multiple tests (90) is .49 for a p-value of 0.01 and 0.60 for a p-value of 0.001; with Bonferroni adjustments for multiple tests, the critical p-value is 0.73 for a rho of 0.05. Correlations greater than the Bonferroni adjusted number are in **bold**; dark green indicates $p \leq 0.001$; green indicates $p \leq 0.01$, light green indicates $p \leq 0.05$. Characteristic abbreviations are listed in appendixes 1-2 and 1-7.]

GIS characteristics	SPMD toxicity, microtox assay	SPMD toxicity, CYP1A1 production	SPMD toxicity, ultraviolet fluorescence	Benzo(a)pyrene	Fluoranthene	Phenanthrene	Pyrene	Penta-chloroanisole	Total number of detects
	EC50	TEQ	UPAH	S_BAPYR	S_FLUOR	S_PHENA	S_PYRE	S_PCA	
UII	0.03	**0.87**	**0.86**	**0.81**	**0.89**	**0.87**	**0.89**	0.52	**0.75**
ROADDEN	.07	**.79**	**.79**	**.80**	**.82**	**.82**	**.83**	.45	.69
RDAREAINDX	.24	.63	.66	**.76**	.66	.67	.66	.14	.58
RDTRAFINDX	.26	.60	.66	**.73**	.65	.66	.65	.18	.56
NLCD_IS	.12	**.85**	**.87**	**.79**	**.86**	**.85**	**.87**	.49	**.75**
P_NLCD1_2	.05	**.82**	**.86**	**.80**	**.85**	**.84**	**.86**	.46	.72
PNLCD21	-.16	**.77**	**.81**	**.77**	**.80**	**.80**	**.80**	.34	.66
PNLCD22	.06	**.79**	**.81**	**.80**	**.82**	**.80**	**.82**	.42	.69
PNLCD23	.13	**.82**	**.85**	**.75**	**.84**	**.83**	**.84**	.49	.70
PNLCD24	.07	**.89**	**.86**	**.80**	**.87**	**.83**	**.87**	.49	**.79**
POPDENKM	.05	**.89**	**.88**	**.80**	**.88**	**.88**	**.88**	.48	**.73**
HUDEN	.06	**.85**	**.88**	**.81**	**.85**	**.84**	**.86**	.46	.72
PLA_U	.07	**.84**	**.86**	**.79**	**.87**	**.85**	**.87**	.50	**.75**
PAM_NU	-.02	**-.82**	**-.81**	**-.74**	**-.80**	**-.79**	**-.81**	-.47	-.72

The toxicity potential measured through TEQ and UPAH, benzo(a)pyrene, fluoranthene, phenanthrene, and pyrene concentrations, showed strong, positive correlations (rho values greater than 0.79) with landscape variables related to impervious area, road density, high-density development in the watershed, census variables related to population and housing density, and increases in density and mean area of patches of urban land cover, and especially the proportion/percentage of patch adjacencies that are developed (urban) (PLA_U). Toxicity potential (TEQ and UPAH) and PAH concentrations increased as the percentage of total impervious surface of the watershed increased. Concentrations, potential toxicity, and variability increased for these compounds when the impervious surface in the watershed was greater than 8 percent (fig. 29*A*, *B*). The road area and traffic index (fig. 29*C*) plotted against percentage of impervious surface indicated that large changes in these road indices corresponded with similar changes in PAH concentrations (fig. 29*B*). Also, decreases in PAH concentrations for sites with greater percentages of impervious surface corresponded with decreases in road area and traffic indices. The variability in concentrations of the PAH compounds between 19 and 26 percent impervious surface could be due to less road area and traffic index at these sites, compared to the other sites with impervious surface greater than 10 percent. The average yield of PAHs from parking lots with coal-tar-based sealcoats is 50 times greater than that from unsealed lots (Mahler and others, 2005). The four PAH compounds benzo(a)pyrene, fluoranthene, phenanthrene, and pyrene not only are associated as components of petroleum products but also have been identified with commercial sealcoat (Mahler and others, 2005). The study findings support the idea that PAHs would be found in greater numbers in urban areas with toxicity potential and PAH variables that show more and stronger correlations with urban variables than any other chemistry variable. The strong positive correlation with impervious surfaces, infrastructure variables, high-density urban land cover, and land-distribution variables related to urbanization indicate that automobiles and infrastructure to support automobiles are a significant source of PAHs in the study area.

One other compound was positively identified in more than half of the SPMD results. Beta-sitosterol is a phytosterol found in plants; it was detected more often (23 of 27) than any other variable but did not correlate with any landscape variables. The insecticide chlorpyrifos was detected only at four sites, with the highest concentration (596 nanograms per SMPD) found at the same site (Black Creek, UII = 4.18) that showed an exceedance of water-quality criteria for chlorpyrifos for the August water sample.

Biology

Relations to environmental characteristics were examined separately for each group of biota using assemblage relative abundance data and metrics derived from this data. Assemblage relative abundance data and metrics for each group showed relations to urbanization. Each environmental characteristic used in final multivariate analyses represented at least one other less-important environmental characteristic that was excluded to minimize effects of intercorrelation (rho ≥ 0.8) in later model runs. For example, total impervious surface in the watershed was the representative characteristic for the percentages of high- and medium-intensity developed land in the 100-m riparian zone or watershed, the ratio of developed open land to all developed land, and chloride concentration. Watershed impervious surface also was used to represent impervious surface in the 100-m riparian zone in multivariate analyses.

Algae

The RTH algal assemblage at the 30 streams consisted of 201 separate algal taxa. The majority of taxa in the overall RTH algal assemblage were in the diatom group, with a total of 171 taxa. At each stream, an average of 42 taxa was found. The highest number of taxa (taxa richness) was at Mud Creek, with 62 taxa; the lowest richness was at Pigeon Creek, with 27 taxa. Three species of diatoms found at all sites were *Amphora pediculus*, *Navicula minima*, and *Nitzschia inconspicua*. An unknown blue-green and an unknown red algal taxon also were present at all but one site: the exception was Lincoln Creek, the most urban stream.

Based on relative abundance, the RTH algal assemblages of Lincoln Creek and Ashwaubenon Creek were vastly different than those of other sites in the study. The assemblage at Lincoln Creek was dominated strongly by the blue-green algae *Homoeothrix janthina* that composed 85.4 percent of the total abundance. This filamentous alga was not found at any other site in the study area: in related studies, this species was found in cold, oligotrophic, and fast-flowing streams with low urbanization (Potapova and others, 2005). A major stream-restoration project completed about two years prior to this Wisconsin study included channel restructuring, streambed removal/replacement, and removal of all riparian vegetation. The lack of any tree canopy, together with high levels of nutrients (nitrogen and phosphorus) and less flow per area than streams with low levels of urbanization, could have contributed to an abundance of early-colonizer algal species such as the blue-green *H. janthina*. An unknown red alga (Florideophycidae chantransia) dominated the algal assemblage at Ashwaubenon Creek, representing 46.0 percent of the total abundance. Because this red alga could not be identified below the phylum level, preferred environmental characteristics of this alga could not be determined; it was not found at any other site in this study.

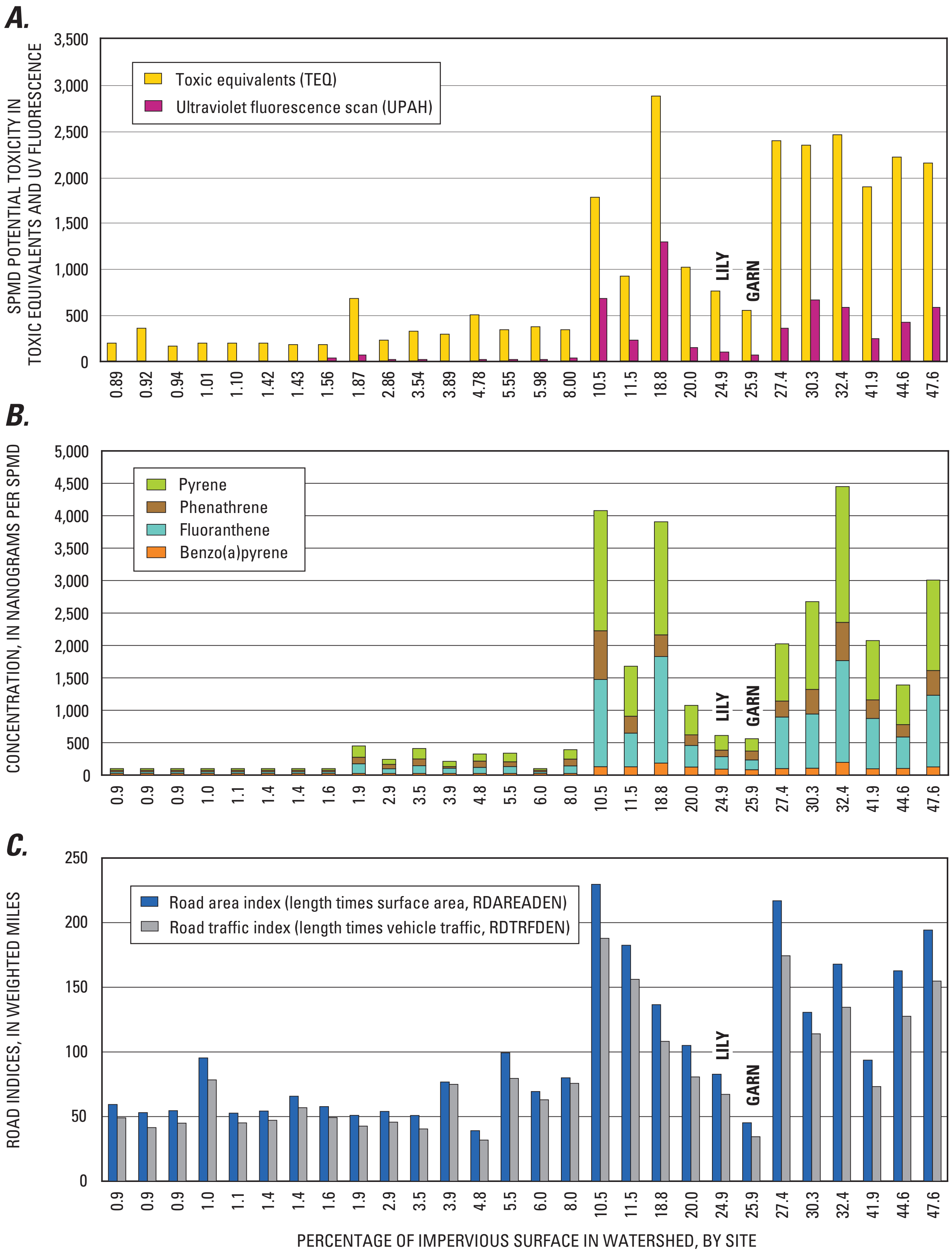


Figure 29. Relation between percentage of impervious surface in watershed and *A*, semipermeable membrane device (SPMD) potential toxicity, *B*, SPMD polycyclic aromatic hydrocarbon (PAH) chemistry, and *C*, road indices for 28 study sites in the Milwaukee to Green Bay, Wis., study area.

The calculated RTH algal metrics (table 15) showed many linear correlations to the environmental characteristics but did not correlate directly to the UII. The RTH algal metrics that showed the most relations with environmental characteristics were salinity tolerance, saprobic (nutrient and oxygen saturation) conditions, oxygen requirement, Bahls' pollution-tolerance classes, and nitrogen-uptake metabolism (appendix 3) (Bahls, 1993). The functional group of RTH algae that are considered pollution sensitive (PC_SN) and those that are intolerant of dissolved oxygen saturations of less than 75 percent (OT_FH) showed strong negative correlations to indicators of urban impact such as watershed impervious surface (NLCD_IS), household density (HHDEN), road area density (RDARDEN), specific conductance (SPCOND), and chloride (CHLOR) (all $p<0.001$). These metrics also showed strong positive relations to non-urban characteristics, including percentage of wetlands in the watershed (P_NLCD1_9), percentage of forest in the watershed (P_NLCD1_4), soils with high-range permeability (PERM), and bicarbonate (BICARB) (all $p<0.001$) (appendix 3).

Each of the algal functional groups was highly correlated with GIS-derived characteristics for natural environmental setting and degree of urbanization, hydrology, and water chemistry in spring and summer. The percentage of pollution-sensitive diatoms (PC_SN) decreased as the percentage of total impervious surface in the watershed (NLCD_IS) increased (rho = -0.56). There were no sites with greater than 20 percent total impervious surface in the watershed that had greater than 70 percent of the algal assemblage composed of pollution-sensitive algae (fig. 30*A*).

With the exception of the Kewaunee River Tributary, diatoms that are tolerant of low dissolved oxygen saturation (less than 30 percent) (OT_LW) increased as the runs in the stream reach (GCUTypeRunPct) increased (rho = 0.49) (fig. 30*B*). The Kewaunee River Tributary is a small stream and had the smallest mean wetted width, the second lowest dissolved oxygen value, and one of the lowest average discharges. These characteristics combined, with 70 percent of runs in the reach, may explain the unusually high percentage of low-oxygen diatoms in the stream.

The metric OT_FH decreased as the post-ice hydrological metric periodr9 (an indicator of flashiness and frequent substantial hydrograph rises) increased (rho = -0.68) (fig. 30*C*). This relation is possibly a result of the scouring of a stream's benthic assemblage that occurred during these flashy flood events (Sousa, 1984). Increases in water volume and velocity of the streams may increase dissolved oxygen concentration; however, rapid changes in these streamflow attributes simply may scour the algal cells from the substrate and wash them downstream.

Halobiontic diatoms (SL_HB diatoms prefer salinities greater than 500 mg/L of chloride) showed a strong positive correlation to the spring chloride concentration (CHLOR) (rho = 0.66) (fig. 30*D*). Three sites—Kilbourn Ditch, Little Menomonee River, and Pike River—had higher than expected percentages of these high-salinity diatoms than the trend of the other 27 sites. The spring water-chemistry sample at these sites was taken when the flows were high (at or near Q10); this may have caused a dilution of the chloride in the samples (Clinton and Vose, 2006).

Pollution-sensitive diatoms (PC_SN) showed a strong positive correlation to bicarbonate concentration (BICARB) in the summer water sample (rho = 0.57) (fig. 30*E*). The sites with greater than 65 percent pollution-sensitive diatoms and greater than 79 mg/L bicarbonate concentration were in watersheds with greater than 4.26 percent wetlands. This may explain why Ashwaubenon Creek did not seem to follow the trend of the other sites. The watershed contributing to Ashwaubenon Creek includes 1.25 percent wetlands; where other sites with similar bicarbonate concentrations have a minimum of 2.86 percent wetlands. Pollution-sensitive diatoms were also significantly correlated to the percentage of wetlands in the watershed (P_NLCD1_9) (rho = 0.70); this relation of pollution-sensitive diatoms to bicarbonate may be a secondary response of the bicarbonate concentration to watershed wetlands.

Pollution-sensitive diatoms showed a significant negative relation (rho = -0.65) to the SPMD analyte pentachloroanisole (PCA) that is produced by the microbial methylation of the antifungal wood preservative pentachlorophenol (fig. 30*F*). The SPMD from Pigeon Creek contained the highest concentration of PCA but the algal assemblage for the creek still maintained 83.62 percent pollution-sensitive diatoms. The biological effects of this analyte may be obscured because of environmental characteristics in the watershed such as high percentage of forest and wetlands and low percentage of developed land in the 100-m riparian zone.

The DTH algal assemblage for the 30 sites was composed of 256 separate algal taxa. Diatoms dominated the assemblages at most sites for 236 species for all streams. The average algal richness at each stream was 56 taxa. The highest taxa richness was at Kewaunee River Tributary, with 82 taxa; the lowest richness was at Pike Creek, with 14 taxa. The only species found at all sites was the diatom *Navicula minima*.

Lincoln Creek also showed a different DTH algal assemblage than the other 29 sites; the assemblage included several species not found at any other site. The blue-green *Leptolyngbya* sp. accounted for 63.35 percent of the total relative abundance of algae at Lincoln Creek. This mat-forming, filamentous alga was not found at any other site and is understudied with regard to preferred environmental characteristics.

Table 15. Biological metrics computed from richest targeted habitat algal assemblages for 30 sites in the Milwaukee to Green Bay, Wis., study area.

[Site list is sorted by urban intensity index (UII) values, from lowest to highest. All values are in percent of classified taxa. CellDens_tot values have been divided by 10,000. Site abbreviations are listed in table 1. Metric definitions are listed in appendix 1-8.]

Site abbreviation	NumTax_all	NumTax_dtm	CellDens_tot (10^3)	Percent relative abundance						Pollution class			Pollution tolerance				
				Blue-green algae	Diatoms	Euglenoids	Green algae	Red algae	Unknown phyla	PC_MT	PC_LT	PC_SN	PT_VT	PT_TA	PT_TB	PT_LA	PT_LB
JAMB	50	44	335.38	17.26	43.72	0.00	0.00	9.64	29.37	4.05	9.46	86.49	4.92	1.84	1.23	90.37	1.64
BLAK	39	34	508.51	22.95	66.36	.00	.00	5.68	5.00	5.97	8.86	85.17	6.10	1.42	.00	92.07	.41
MEME	59	54	76.20	17.44	70.23	.00	.00	5.58	6.74	8.99	17.98	73.03	11.11	.32	.63	81.90	6.03
RIOC	57	52	425.34	29.72	61.36	.00	.00	2.34	6.58	7.47	16.19	76.33	9.33	5.50	.96	82.54	1.67
DEVL	35	30	811.81	53.06	33.78	.00	.00	9.04	4.12	4.71	17.85	77.44	3.25	12.81	.00	83.75	.19
KEWA	50	42	483.47	77.35	3.99	.00	.45	10.68	7.52	31.58	22.32	46.10	38.26	7.26	.48	54.00	.00
BAIR	46	40	167.00	19.27	45.26	.00	.61	33.49	1.38	3.17	35.98	60.85	4.96	8.82	.00	84.85	1.38
POIN	39	35	279.40	47.18	39.41	.00	.00	13.42	.00	3.17	15.50	81.33	3.55	.63	.63	94.36	.84
ASHW	49	45	103.40	25.91	28.10	.00	.00	45.99	.00	35.17	58.75	6.08	34.57	36.70	5.32	7.45	15.96
BLOT	31	25	407.55	61.83	27.54	.00	2.06	5.37	3.20	11.44	11.05	77.51	12.28	3.12	.45	83.93	.22
KILB	29	23	890.49	34.33	62.00	.00	.00	2.28	1.40	12.81	54.91	32.28	24.26	12.13	.00	63.61	.00
HOOD	45	38	230.17	27.83	42.03	.00	.00	20.58	9.57	12.39	38.70	48.91	17.01	3.47	.69	78.13	.69
SAWY	39	34	471.26	62.57	22.71	.00	.00	6.43	8.28	9.87	26.19	63.95	12.19	5.97	.00	81.84	.00
APPL	37	30	82.16	27.94	52.23	.20	.00	1.01	18.62	5.98	48.84	45.18	14.69	1.63	1.22	81.63	.82
LANC	35	30	382.21	44.81	48.82	.00	.00	2.37	4.01	1.94	11.13	86.93	1.98	2.77	.99	92.08	2.18
BOWR	43	39	249.23	18.03	65.20	.00	.00	2.94	13.84	3.92	69.80	26.28	9.37	19.79	2.08	63.54	5.21
FOXR	56	51	394.80	60.19	26.90	.00	.00	6.26	6.66	1.73	14.07	84.20	1.18	4.73	.95	91.02	2.13
MENO	37	32	663.53	26.84	15.27	.00	.00	8.50	49.39	5.86	36.41	57.73	8.39	2.48	.00	89.13	.00
PIGN	28	22	312.42	49.13	41.39	.16	.00	9.16	.16	5.57	10.80	83.62	5.91	.41	.00	93.48	.20
PIKR	40	35	247.25	27.04	51.85	.00	.00	.93	20.19	11.13	55.65	33.22	24.69	.41	.00	74.07	.82
GARN	48	43	77.27	17.81	32.43	.00	.00	25.12	24.64	11.19	50.62	38.19	22.96	4.81	.00	68.89	3.33
LILY	42	37	338.84	27.16	66.50	.00	.00	6.35	.00	3.76	32.08	64.16	5.06	9.88	.24	78.55	6.27
MUDC	62	56	191.49	22.97	35.77	.00	.00	29.27	11.99	4.06	31.55	64.39	5.83	8.06	1.39	76.67	8.06
LTME	31	27	466.21	70.01	22.35	.00	.00	7.64	.00	6.19	57.70	36.11	13.13	3.09	.77	82.63	.39
UNDW	50	43	94.71	13.98	46.24	.00	.72	7.35	31.72	1.73	30.28	67.99	3.01	19.92	1.50	71.05	4.51
OAKC	38	34	473.90	53.86	29.96	.00	.00	7.08	9.10	9.52	56.79	33.69	22.36	2.95	.84	73.84	.00
PIKC	43	38	491.95	37.84	55.99	.00	.68	2.91	2.57	4.60	42.91	52.49	7.44	10.71	.60	80.95	.30
HONY	36	31	26.62	13.32	20.78	.00	.18	12.61	53.11	8.59	61.86	29.55	22.87	12.77	.00	62.23	2.13
ROOT	43	38	123.74	37.86	26.30	.00	.00	17.09	18.76	5.81	46.28	47.91	10.42	12.50	1.74	75.00	.35
LINC	37	28	1,593.84	90.08	6.27	.00	3.65	.00	.00	9.57	76.77	13.65	41.86	9.30	.00	41.09	7.75

Table 15. Biological metrics computed from richest targeted habitat algal assemblages for 30 sites in the Milwaukee to Green Bay, Wis., study area—Continued.

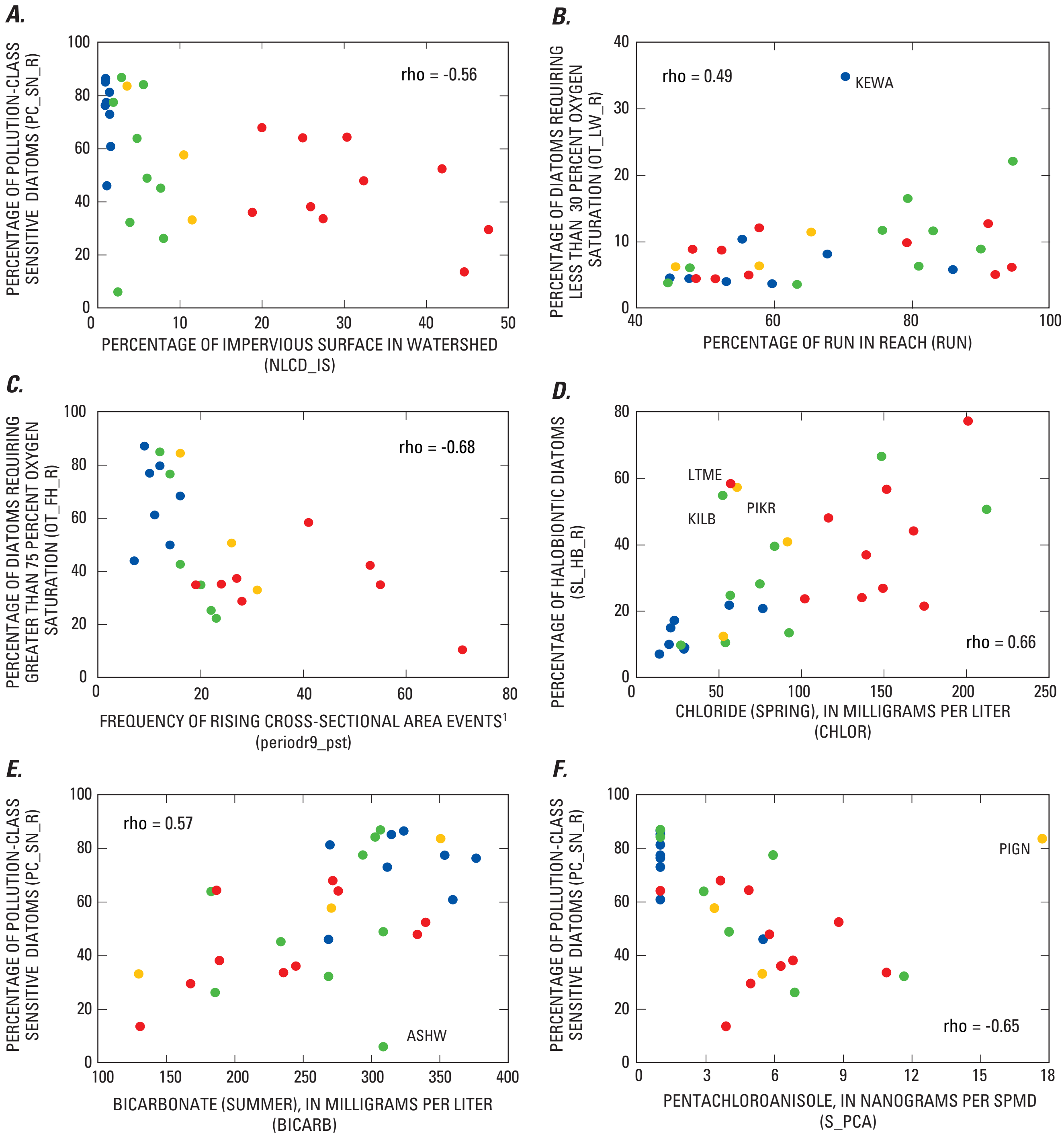
[Site list is sorted by urban intensity index (UII) values, from lowest to highest. All values are in percent of classified taxa. CellDens_tot values have been divided by 10,000. Site abbreviations are listed in table 1. Metric definitions are listed in appendix 1-8.]

Site abbreviation	Saprobity					Trophic condition								
	SP_OL	SP_BM	SP_AM	SP_AP	SP_PS	TR_OL	TR_OM	TR_MT	TR_ME	TR_ET	TR_PT	TR_EY	TR_E	TR_O
JAMB	1.71	88.72	3.25	6.32	0.00	0.34	0.51	1.86	3.89	82.57	0.00	10.83	86.46	0.85
BLAK	7.81	82.51	3.57	6.11	.00	.17	.68	.17	1.02	87.12	.00	10.85	88.14	.85
MEME	.96	74.42	13.65	10.58	.38	1.75	.00	1.36	2.72	86.77	.58	6.81	90.08	1.75
RIOC	3.51	76.98	10.02	9.49	.00	.88	.18	.70	4.90	83.54	.00	9.81	88.44	1.05
DEVL	.17	80.85	12.14	6.84	.00	1.68	.00	.67	2.52	87.92	.34	6.88	90.77	1.68
KEWA	3.67	46.15	16.96	32.87	.35	2.44	.00	.17	2.79	87.46	.87	6.27	91.11	2.44
BAIR	1.58	67.02	25.26	6.14	.00	.71	.35	.35	3.36	83.04	.18	12.01	86.57	1.06
POIN	.70	82.75	13.24	3.31	.00	3.21	.17	.17	1.69	92.72	.00	2.03	94.42	3.38
ASHW	22.74	14.66	38.53	19.17	4.89	2.99	.00	.00	8.60	65.79	5.05	17.57	79.44	2.99
BLOT	.20	81.23	6.32	12.25	.00	.39	.00	.20	.98	93.11	.20	5.12	94.29	.39
KILB	.00	34.75	52.20	13.05	.00	.34	.00	.00	15.03	83.11	.00	1.52	98.14	.34
HOOD	21.05	43.86	21.40	13.68	.00	.35	.00	.35	33.86	57.19	.18	8.07	91.23	.35
SAWY	1.26	67.15	21.84	9.75	.00	1.27	.00	.00	.90	85.53	.36	11.93	86.80	1.27
APPL	.83	47.17	45.83	6.17	.00	.83	.00	.00	1.33	93.03	.17	4.64	94.53	.83
LANC	1.55	89.14	7.59	1.72	.00	.35	.00	.52	7.97	84.58	.00	6.59	92.55	.35
BOWR	.35	28.35	67.13	4.17	.00	1.04	.00	.69	2.43	93.76	.35	1.73	96.53	1.04
FOXR	6.64	81.37	7.20	2.95	1.85	1.43	3.21	.18	8.93	65.54	1.79	18.93	76.25	4.64
MENO	1.07	57.19	35.17	6.57	.00	1.23	.00	.00	1.05	95.78	.00	1.93	96.84	1.23
PIGN	1.59	85.84	6.55	6.02	.00	2.59	.00	.00	1.38	89.48	.00	6.55	90.86	2.59
PIKR	1.23	35.90	51.66	11.21	.00	.52	.00	.00	2.79	94.25	.00	2.44	97.04	.52
GARN	2.84	41.84	42.20	9.40	3.72	1.22	.17	.70	1.57	84.64	3.66	8.03	89.88	1.40
LILY	.36	71.89	20.82	5.34	1.60	.00	.00	.19	4.65	69.89	1.67	23.61	76.21	.00
MUDC	4.32	70.14	19.60	4.68	1.26	3.27	.00	.73	4.90	79.67	.91	10.53	85.48	3.27
LTME	.88	38.91	53.52	6.69	.00	.00	.18	.18	5.10	92.09	.00	2.46	97.19	.18
UNDW	1.75	70.23	20.32	7.71	.00	.70	.00	.00	1.40	86.36	.35	11.19	88.11	.70
OAKC	4.12	34.19	51.03	10.31	.34	1.19	.17	.00	4.25	88.78	.34	5.27	93.37	1.36
PIKC	1.88	53.66	36.96	5.25	2.25	.75	.00	1.49	1.12	71.64	.75	24.25	73.51	.75
HONY	.69	30.76	41.07	27.49	.00	.85	.00	.68	2.39	76.58	.00	19.49	78.97	.85
ROOT	3.75	46.25	24.11	25.18	.71	.00	.00	1.07	.54	72.63	.36	25.40	73.52	.00
LINC	2.65	12.87	72.13	11.99	.35	2.81	.00	.18	2.81	88.22	.70	5.27	91.74	2.81

Table 15. Biological metrics computed from richest targeted habitat algal assemblages for 30 sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[Site list is sorted by urban intensity index (UII) values, from lowest to highest. All values are in percent of classified taxa. CellDens_tot values have been divided by 10,000. Site abbreviations are listed in table 1. Metric definitions are listed in appendix 1-8.]

Site abbreviation	Salinity					Oxygen preference			Organic nitrogen				
	SL_FR	SL_FB	SL_BF	SL_BR	SL_HB	OT_FH	OT_MD	OT_LW	ON_AL	ON_AH	ON_HF	ON_HO	ON_NH
JAMB	1.18	96.30	2.35	0.17	2.52	75.86	11.53	4.50	2.15	91.58	6.27	0.00	6.27
BLAK	7.60	89.36	2.70	.34	3.04	87.21	5.33	5.86	8.19	82.92	8.54	.36	8.90
MEME	.93	90.13	8.94	.00	8.94	50.00	36.73	10.41	1.03	89.12	6.98	2.87	9.86
RIOC	2.58	93.46	2.58	1.38	3.96	68.42	18.32	8.19	4.07	82.36	13.57	.00	13.57
DEVL	.17	98.83	1.01	.00	1.01	76.99	16.46	4.60	1.06	81.77	16.46	.71	17.17
KEWA	3.64	80.59	15.60	.17	15.77	44.01	19.48	34.83	1.31	51.87	44.76	2.06	46.82
BAIR	1.20	84.02	14.78	.00	14.78	61.27	33.53	4.05	1.54	76.45	21.81	.19	22.01
POIN	.00	88.81	11.19	.00	11.19	79.75	14.74	3.73	.71	85.20	13.73	.36	14.08
ASHW	5.69	60.73	31.38	2.20	33.58	22.33	15.09	22.13	26.38	48.74	19.10	5.78	24.87
BLOT	.20	96.06	3.74	.00	3.74	76.64	10.45	11.68	.82	81.31	17.66	.21	17.86
KILB	.00	51.09	48.91	.00	48.91	33.73	48.88	16.52	.69	36.98	61.81	.52	62.33
HOOD	2.22	75.60	22.18	.00	22.18	42.68	22.60	11.75	23.95	45.70	29.43	.91	30.35
SAWY	1.80	79.46	18.74	.00	18.74	59.78	20.11	8.94	4.66	63.13	31.66	.56	32.22
APPL	.66	54.61	44.41	.33	44.74	34.90	57.42	6.11	.70	46.23	52.89	.18	53.06
LANC	1.54	94.00	4.46	.00	4.46	85.02	8.48	3.61	2.37	94.54	3.10	.00	3.10
BOWR	.34	38.95	60.71	.00	60.71	25.31	67.26	6.37	.35	35.40	63.54	.71	64.25
FOXR	6.19	86.37	6.02	1.42	7.43	71.95	12.77	3.87	7.35	87.43	4.84	.39	5.22
MENO	1.05	64.04	34.91	.00	34.91	50.71	41.99	6.41	1.25	58.01	40.21	.53	40.75
PIGN	1.21	92.41	6.38	.00	6.38	84.53	7.37	6.26	1.85	86.35	11.81	.00	11.81
PIKR	.69	47.93	51.38	.00	51.38	33.03	55.30	11.49	2.69	33.21	63.91	.18	64.09
GARN	2.57	55.31	41.78	.34	42.12	34.94	49.17	12.75	2.97	44.05	48.33	4.65	52.97
LILY	.35	81.98	16.61	1.06	17.67	50.10	26.77	4.46	1.42	69.98	27.99	.61	28.60
MUDC	3.70	80.81	15.49	.00	15.49	58.43	30.92	5.02	4.23	73.44	21.33	1.01	22.33
LTME	.52	47.03	52.45	.00	52.45	37.35	55.22	6.19	3.36	37.52	59.12	.00	59.12
UNDW	1.22	80.73	18.06	.00	18.06	35.20	56.32	4.51	2.35	78.16	19.13	.36	19.49
OAKC	.34	48.90	50.42	.34	50.76	28.75	55.03	9.88	4.59	34.22	60.85	.35	61.20
PIKC	1.87	67.16	26.31	4.66	30.97	34.97	36.86	5.10	1.70	62.19	35.35	.76	36.11
HONY	.17	61.67	37.31	.85	38.16	21.17	68.50	8.78	2.24	49.57	48.19	.00	48.19
ROOT	3.75	75.36	20.54	.36	20.89	42.29	47.19	8.89	3.81	73.32	22.50	.36	22.87
LINC	2.46	26.19	71.35	.00	71.35	10.49	74.32	12.12	1.27	17.36	81.01	.36	81.37



[1] When total rise of cross-sectional area is greater than or equal to 9 times the median total rise over the post-ice period of record (March 16–October 20, 2004).

Figure 30. Relations between selected richest targeted habitat algal metrics and selected environmental characteristics for 30 study sites in the Milwaukee to Green Bay, Wis., study area.

The calculated algal metrics for the DTH samples (table 16) showed many similar correlations to environmental characteristics, as did the RTH samples; they did not, however, correlate directly to the UII. The DTH algal metrics that showed the most relations with environmental characteristics were salinity tolerance, saprobic (nutrient and oxygen saturation) conditions, oxygen requirement, Bahls' pollution-tolerance classes, and nitrogen uptake metabolism (appendix 4) (Porter, 2008). The functional groups of DTH algae that are considered halobiontic (SL_HB) showed strong positive correlations to indicators of urban impact such as watershed impervious surface (NLCD_IS), urban land covers (P_NLCD1_2), population density (POPDEN00), household density (HHDEN), road area density (RDARDEN), and chloride (CHLOR) (all $p<0.05$). The DTH algal metrics of percentage of pollution-sensitive diatoms and those that require greater than 75 percent dissolved oxygen saturation (OT_FH) show strong positive relations to non-urban characteristics, including percentage of wetlands in the watershed (P_NLCD1_9), proximity of forests (PIM_C4), and percent pasture/hay in the watershed (PNLCD_81) (all $p<0.05$).

The percentage of diatoms in the DTH samples requiring greater than 75 percent dissolved oxygen saturation (OT_FH) decreased with an increase of high-intensity developed land cover in the watershed (P_NLCD_24) (fig. 31*A*). This highly significant relation indicated that all sites with greater than 5 percent high-intensity developed land cover had less than 30 percent OT_FH diatoms (rho = -0.61).

The percentage of pollution-class most tolerant diatoms (PC_MT) decreases with increasing reach slope (RCHSLOPE) (fig. 31*B*). This highly significant correlation indicates that streams with lower slopes support algal assemblages that can tolerate higher pollution loads (rho = -0.62). Additionally, as discussed in the habitat section, reach slope also was highly correlated with the percentage of riffles in the reach; therefore suggesting that low-gradient streams with few riffles were more likely to have pollution-tolerant algal assemblages.

The percentage of brackish-water diatoms (SL_BR) decreased as bankfull discharge (normalized by drainage area) (Q_bnkflDA) increased (fig. 31*C*). These diatoms, that can tolerate salinity ranges of 1,000 to 5,000 mg/L of chloride and 1.8 to 9.0 parts per thousand of salinity, are found in higher percentages at the streams with higher discharges.

Halobiontic diatoms (SL_HB; prefer salinities greater than 500 mg/L of chloride), showed a strong negative relation to the spring dissolved organic carbon concentrations (DISORGC) (rho = -0.66) (fig. 31*D*). This relation is a result of the spring runoff where the areas that have higher concentrations of salinity in the snowmelt will have lower concentrations of dissolved organic carbon. These watersheds are more urbanized with higher percentages of road area and do not have the carbon sources that less-urbanized watersheds would have.

The percentage of diatoms associated with eutrophic conditions (TR_E) showed a negative correlation to the concentration of bicarbonate (BICARB) in the summer surface-water samples (rho = 0.53) (fig. 31*E*). Streams with more wetlands in the watershed may have higher bicarbonate concentrations that act as a sink for nutrients, decreasing the likelihood of eutrophic conditions.

Multivariate analyses of relations between algal assemblages and environmental characteristics indicated relations were stronger for the DTH algal assemblage compared to the RTH assemblage. In addition, relations were stronger when all species were included, compared to relations when rare taxa were excluded. Urban- and non-urban-associated characteristics were correlated to variation in DTH algal assemblages in this study (fig. 32). In order of priority, the characteristics most influencing DTH algal assemblages were woody wetlands in the watershed, nitrate concentration, percentage of runs in the reach, bicarbonate concentration, total impervious surface in the watershed, maximum instantaneous peak flow normalized by drainage area, sulfate concentration, number of herbicide detections, mean watershed slope, total phosphorus concentration, open canopy angle, percentage of stream bank vegetative cover in the reach, channel-shape coefficient, streambed-substrate stability, and the discharge exceeded 50 percent of the time. Positive Spearman rank correlations were found between algal assemblages and total concentrations of nitrogen; however, correlations to nitrate were higher. For this reason and because of intercorrelations between total nitrogen and nitrogen fractions, nitrate was used as a representative in multivariate ordinations. Lincoln Creek was an outlier in ordinations of RTH and DTH algal assemblages, primarily because of the different species assemblage (mentioned earlier), the lack of a vegetative canopy in the reach, and higher values for maximum instantaneous peak flows. For ordinations using all 30 sites, eigenvalues for axes 1 through 4 were 0.351, 0.256, 0.160, and 0.137, respectively; Monte Carlo permutations tests showed that all axes were significant. The eigenvalue for axis 1 decreased to 0.261 when Lincoln Creek was excluded, but the significance increased and the species-environment correlation increased.

Table 16. Biological metrics computed from depositional-targeted habitat algal assemblages for 30 sites in the Milwaukee to Green Bay, Wis., study area.

[Site list is sorted by urban intensity index (UII) values, from lowest to highest. All values are in percent of classified taxa. CellDens_tot values have been divided by 10,000. Site abbreviations are listed in table 1. Metric definitions are listed in appendix 1-8.]

Site abbreviation	NumTax_all	NumTax_dtm	CellDens_tot (10^3)	Percent relative abundance						Pollution class			Pollution tolerance				
				Blue-green algae	Diatoms	Euglenoids	Green algae	Red algae	Unknown phyla	PC_MT	PC_LT	PC_SN	PT_VT	PT_TA	PT_TB	PT_LA	PT_LB
JAMB	79	74	234	19.4	73.0	0.38	0.00	0.00	7.22	3.36	53.5	43.2	6.40	11.2	19.2	55.6	7.60
BLAK	59	56	307	28.3	67.7	.00	.00	.00	4.04	6.62	27.0	66.4	8.27	8.79	.00	78.8	4.13
MEME	75	71	142	43.9	53.2	.00	.00	2.92	.00	11.8	49.7	38.5	19.2	16.0	8.45	47.4	8.92
RIOC	60	54	273	38.6	58.7	1.32	.00	.00	1.32	23.2	42.0	34.7	35.3	6.99	.37	53.3	4.04
DEVL	60	57	108	21.3	67.2	.00	.00	.00	11.5	1.40	49.00	49.60	3.01	12.8	5.64	76.7	1.88
KEWA	82	78	346	73.2	26.8	.00	.00	.00	.00	19.7	49.7	30.6	26.2	27.6	10.0	34.8	1.38
BAIR	55	52	280	19.8	79.2	.00	.00	.97	.00	4.64	54.6	40.7	8.18	24.8	4.24	54.8	7.88
POIN	66	64	69.9	33.3	66.7	.00	.00	.00	.00	4.90	40.3	54.8	5.64	15.1	6.23	68.5	4.45
ASHW	41	37	66.2	54.5	38.1	.00	.00	7.46	.00	50.2	43.7	6.05	16.0	60.0	14.7	8.00	1.33
BLOT	61	56	128	63.8	28.6	.00	2.16	1.08	4.32	6.28	24.9	68.8	9.32	10.4	5.02	72.4	2.87
KILB	50	46	497	35.6	61.9	.00	.00	.00	2.54	21.3	69.5	9.16	32.8	39.7	1.72	24.7	1.15
HOOD	73	70	136	53.0	47.0	.00	.00	.00	.00	5.91	85.21	8.87	5.94	66.8	14.3	11.2	1.75
SAWY	29	24	82.9	41.0	56.6	.00	.00	2.46	.00	36.0	56.2	7.87	56.3	28.1	3.12	12.5	.00
APPL	48	45	88.5	44.8	53.7	.00	.00	1.49	.00	3.11	19.6	77.3	6.12	7.48	3.74	82.3	.34
LANC	67	63	121	35.4	59.2	.00	.00	.00	5.44	4.81	68.9	26.3	4.44	57.9	10.0	22.4	5.14
BOWR	64	60	389	66.5	32.7	.00	.00	.00	.85	6.56	62.5	31.0	13.0	31.7	8.94	44.7	1.63
FOXR	57	52	1,838	70.9	26.9	.00	.87	.00	1.25	6.22	30.3	63.5	9.29	26.2	10.4	49.2	4.92
MENO	59	57	67.7	11.8	80.4	.00	.00	7.84	.00	5.93	37.5	56.6	9.51	18.6	2.28	66.5	3.04
PIGN	79	75	777	68.4	31.3	.24	.00	.00	.00	10.6	44.0	45.4	12.5	16.2	16.5	47.9	7.01
PIKR	48	43	176	29.2	66.9	.00	.00	.00	3.90	11.5	67.0	21.5	25.3	18.6	1.03	55.2	.00
GARN	55	51	108	61.9	36.1	.00	.00	2.06	.00	31.1	58.8	10.1	40.7	32.3	1.20	23.4	2.40
LILY	44	41	441	70.7	26.6	.00	.00	2.70	.00	5.23	45.5	49.3	8.98	9.28	.00	81.4	.30
MUDC	50	47	112	73.0	24.8	.00	.00	.00	2.28	28.7	51.0	20.2	33.7	30.2	1.05	33.3	1.75
LTME	51	49	33.8	55.6	44.4	.00	.00	.00	.00	17.1	71.2	11.7	16.0	59.1	2.95	21.9	.00
UNDW	64	60	175	42.5	54.3	.00	.00	1.81	1.36	6.51	42.0	51.5	10.3	27.3	4.74	54.9	2.77
OAKC	53	50	115	23.8	75.0	.00	.00	1.19	.00	11.3	55.9	32.8	12.5	37.5	9.27	40.7	.00
PIKC	14	12	54.0	57.5	42.5	.00	.00	.00	.00	16.0	49.4	34.6	21.6	23.5	.00	54.9	.00
HONY	45	41	12.5	19.2	59.6	.00	.00	5.77	15.4	12.5	56.3	31.2	28.9	7.84	.00	62.3	.98
ROOT	70	66	240	82.9	16.2	.00	.00	.84	.00	7.88	78.9	13.2	10.1	49.8	20.6	16.0	3.48
LINC	47	41	3,029	77.0	22.0	.00	.99	.00	.00	9.07	67.9	23.0	19.8	25.4	1.02	48.7	5.08

Table 16. Biological metrics computed from depositional-targeted habitat algal assemblages for 30 sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[Site list is sorted by urban intensity index (UII) values, from lowest to highest. All values are in percent of classified taxa. CellDens_tot values have been divided by 10,000. Site abbreviations are listed in table 1. Metric definitions are listed in appendix 1-8.]

Site abbreviation	Saprobity					Trophic condition								
	SP_OL	SP_BM	SP_AM	SP_AP	SP_PS	TR_OL	TR_OM	TR_MT	TR_ME	TR_ET	TR_PT	TR_EY	TR_E	TR_O
JAMB	6.02	43.3	35.3	13.4	1.94	0.57	1.14	3.61	17.1	56.4	1.90	19.4	75.3	1.71
BLAK	9.55	62.2	16.8	11.1	.35	1.79	2.14	.89	8.57	70.0	1.07	15.5	79.6	3.93
MEME	2.62	43.3	36.3	12.7	5.04	2.90	.77	.39	11.6	70.8	5.03	8.51	87.4	3.68
RIOC	11.0	31.4	24.6	32.5	.53	5.32	1.95	.53	9.57	58.7	3.19	20.7	71.5	7.27
DEVL	2.17	77.6	13.6	6.30	.39	.80	.40	1.00	16.8	47.6	.40	33.0	64.8	1.20
KEWA	7.58	34.5	28.9	26.3	2.59	3.65	4.23	.38	7.88	65.8	3.85	14.2	77.5	7.88
BAIR	1.20	52.1	29.1	16.0	1.60	1.61	2.62	.00	12.9	60.1	1.61	21.2	74.6	4.23
POIN	4.20	54.8	31.9	8.59	.57	1.73	2.12	.19	7.69	80.0	.58	7.69	88.3	3.85
ASHW	38.0	14.5	33.9	11.3	2.26	2.27	.00	.00	2.27	82.7	2.27	10.5	87.3	2.27
BLOT	5.64	71.4	13.9	8.24	.87	2.56	4.48	1.71	4.05	79.7	.85	6.61	84.6	7.04
KILB	11.2	11.0	60.7	10.3	6.79	7.33	.00	1.88	3.95	73.1	7.52	6.20	84.6	7.33
HOOD	4.74	18.0	71.16	4.36	1.71	2.91	2.71	.78	7.17	81.8	1.94	2.71	90.9	5.62
SAWY	18.9	18.9	40.0	15.8	6.32	5.21	.00	2.08	1.04	80.2	6.25	5.21	87.5	5.21
APPL	.35	80.2	12.0	6.88	.53	1.04	.00	.17	2.95	86.8	.52	8.51	90.3	1.04
LANC	5.94	28.6	59.0	3.53	2.97	1.28	.00	2.55	12.8	75.4	2.91	5.10	91.1	1.28
BOWR	1.21	36.0	42.5	17.9	2.41	.99	.00	.40	7.14	72.6	2.38	16.5	82.1	.99
FOXR	6.80	51.5	28.5	6.80	6.47	.50	.25	2.52	6.55	69.5	5.04	15.6	81.1	.76
MENO	1.02	56.6	33.8	8.55	.00	2.40	.00	.20	5.00	87.0	.00	5.40	92.0	2.40
PIGN	8.68	46.8	32.5	6.04	6.04	.90	5.73	2.33	12.2	61.1	5.73	12.0	79.0	6.63
PIKR	5.38	21.3	62.2	6.27	4.84	3.40	.00	.72	6.98	78.9	4.83	5.19	90.7	3.40
GARN	22.8	13.2	46.9	11.7	5.40	5.71	.00	.18	1.07	76.8	6.07	10.2	83.9	5.71
LILY	1.38	52.2	37.4	6.57	2.42	1.21	.34	.69	7.24	57.4	2.59	30.5	67.2	1.55
MUDC	14.7	22.8	42.3	17.0	3.21	5.23	.19	.19	1.74	74.6	3.68	14.3	80.0	5.43
LTME	12.5	19.7	56.3	8.09	3.47	6.86	.00	.00	5.71	74.5	3.43	9.52	83.6	6.86
UNDW	2.07	53.7	26.0	18.3	.00	1.31	.19	.19	1.50	81.1	.00	15.7	82.6	1.50
OAKC	14.1	31.9	37.5	15.0	1.52	.86	.00	1.94	13.8	75.3	.86	7.31	89.9	.86
PIKC	8.99	33.7	43.8	5.62	7.87	8.16	9.18	.00	.00	46.9	7.14	28.6	54.1	17.35
HONY	2.01	33.8	32.3	31.4	.55	1.64	.00	.55	4.36	73.5	.73	19.3	78.5	1.64
ROOT	6.22	16.9	53.8	21.7	1.41	1.36	.58	.97	9.88	66.5	.58	20.2	76.9	1.94
LINC	7.46	24.9	37.7	29.1	.96	7.49	.00	1.15	2.69	73.1	11.9	3.65	87.7	7.49

Table 16. Biological metrics computed from depositional-targeted habitat algal assemblages for 30 sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[Site list is sorted by urban intensity index (UII) values, from lowest to highest. All values are in percent of classified taxa. CellDens_tot values have been divided by 10,000. Site abbreviations are listed in table 1. Metric definitions are listed in appendix 1-8.]

Site abbreviation	Salinity					Oxygen preference			Organic nitrogen				
	SL_FR	SL_FB	SL_BF	SL_BR	SL_HB	OT_FH	OT_MD	OT_LW	ON_AL	ON_AH	ON_HF	ON_HO	ON_NH
JAMB	4.92	86.7	4.19	4.19	8.38	38.6	45.2	6.61	6.57	87.9	5.34	0.21	5.54
BLAK	8.80	82.9	8.12	.17	8.29	68.4	15.1	11.3	8.24	79.5	10.9	1.34	12.3
MEME	1.69	71.9	24.3	2.07	26.4	30.9	51.4	14.6	1.98	82.9	11.2	3.96	15.2
RIOC	7.93	87.2	4.48	.34	4.83	31.0	35.4	26.3	6.58	68.9	23.2	1.35	24.6
DEVL	1.55	92.2	5.83	.39	6.21	65.6	20.3	4.34	6.01	83.9	10.1	.00	10.1
KEWA	5.73	71.3	20.9	2.03	22.9	30.4	33.1	30.4	5.12	67.0	25.2	2.67	27.8
BAIR	1.15	80.5	17.4	.96	18.4	47.8	34.4	14.8	1.62	77.1	19.4	1.85	21.2
POIN	.74	74.5	24.8	.00	24.8	49.4	30.9	10.7	3.89	76.4	18.2	1.43	19.7
ASHW	2.68	73.2	23.2	.89	24.1	15.5	10.8	21.6	39.0	42.6	15.9	2.56	18.5
BLOT	2.90	81.8	14.5	.83	15.3	48.2	33.3	10.4	3.37	88.9	6.75	.96	7.71
KILB	10.2	34.9	52.1	2.74	54.8	16.0	51.7	25.1	4.57	23.1	61.7	10.6	72.3
HOOD	1.58	42.1	55.1	1.23	56.3	16.2	34.2	40.5	5.05	80.9	11.4	2.64	14.1
SAWY	8.33	57.3	29.2	5.21	34.4	12.2	32.2	28.9	18.1	33.7	39.8	8.43	48.2
APPL	.17	70.9	28.3	.69	29.0	41.5	47.8	6.91	.37	93.7	5.35	.55	5.90
LANC	3.66	45.9	48.0	2.44	50.4	26.0	16.1	52.5	6.64	89.3	3.62	.40	4.02
BOWR	.93	63.6	31.8	3.72	35.5	30.3	49.8	18.4	2.13	68.4	28.1	1.28	29.4
FOXR	5.16	55.5	34.9	4.42	39.3	35.3	37.6	14.9	7.12	79.0	9.83	4.07	13.9
MENO	.19	71.0	28.8	.00	28.8	39.7	45.6	10.8	2.12	68.6	29.3	.00	29.3
PIGN	2.83	74.2	20.5	2.47	23.0	37.3	36.5	15.3	8.70	79.9	7.25	4.14	11.4
PIKR	4.89	37.9	57.2	.00	57.2	24.6	56.5	15.5	3.28	26.8	62.8	7.13	69.9
GARN	7.41	50.2	40.7	1.72	42.4	17.9	42.0	19.5	16.6	25.4	50.9	7.10	58.0
LILY	1.89	59.4	37.5	1.20	38.7	24.0	37.2	9.93	.37	60.1	37.8	1.65	39.5
MUDC	6.54	63.7	29.2	.56	29.7	20.6	27.3	30.7	10.4	41.3	43.9	4.45	48.3
LTME	7.47	40.3	49.4	2.91	52.3	22.0	30.6	33.9	6.76	51.5	37.8	3.96	41.7
UNDW	2.03	72.9	25.1	.00	25.1	28.6	51.5	13.9	1.54	83.6	14.9	.00	14.9
OAKC	3.34	59.5	36.7	.42	37.2	29.2	31.8	20.2	15.4	52.0	31.8	.88	32.7
PIKC	8.00	64.0	28.0	.00	28.0	17.3	33.3	13.6	.00	38.3	53.1	8.64	61.7
HONY	1.62	67.5	30.5	.36	30.9	23.8	60.8	12.8	5.49	50.5	43.4	.55	44.0
ROOT	2.84	60.6	35.0	1.52	36.6	23.7	42.6	27.5	6.68	65.8	27.1	.42	27.6
LINC	8.60	45.7	44.0	1.72	45.7	23.0	36.9	25.3	2.07	34.9	61.4	1.66	63.1

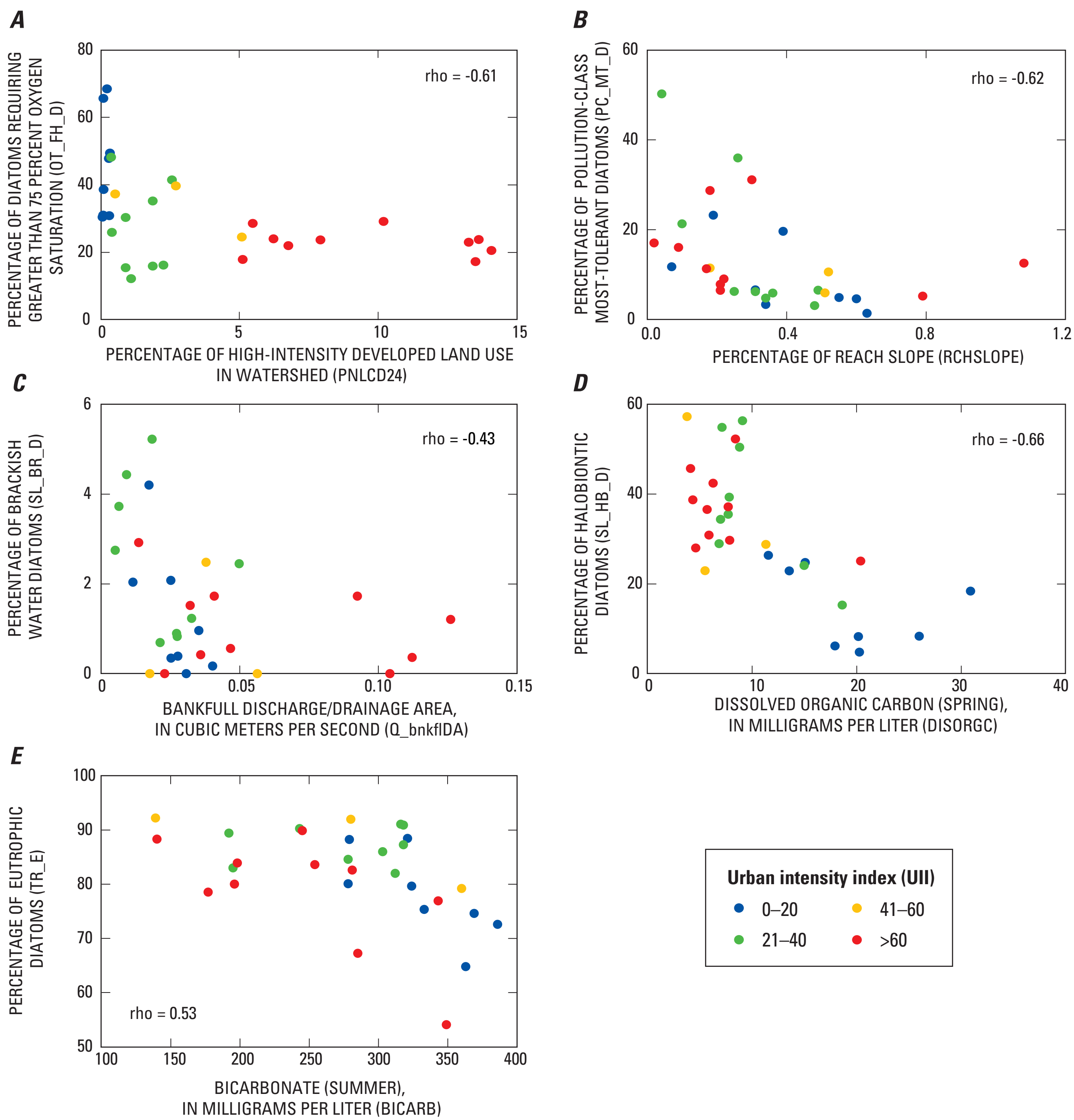


Figure 31. Relations between selected depositional-targeted habitat algal metrics and selected environmental characteristics for 30 study sites in the Milwaukee to Green Bay, Wis., study area.

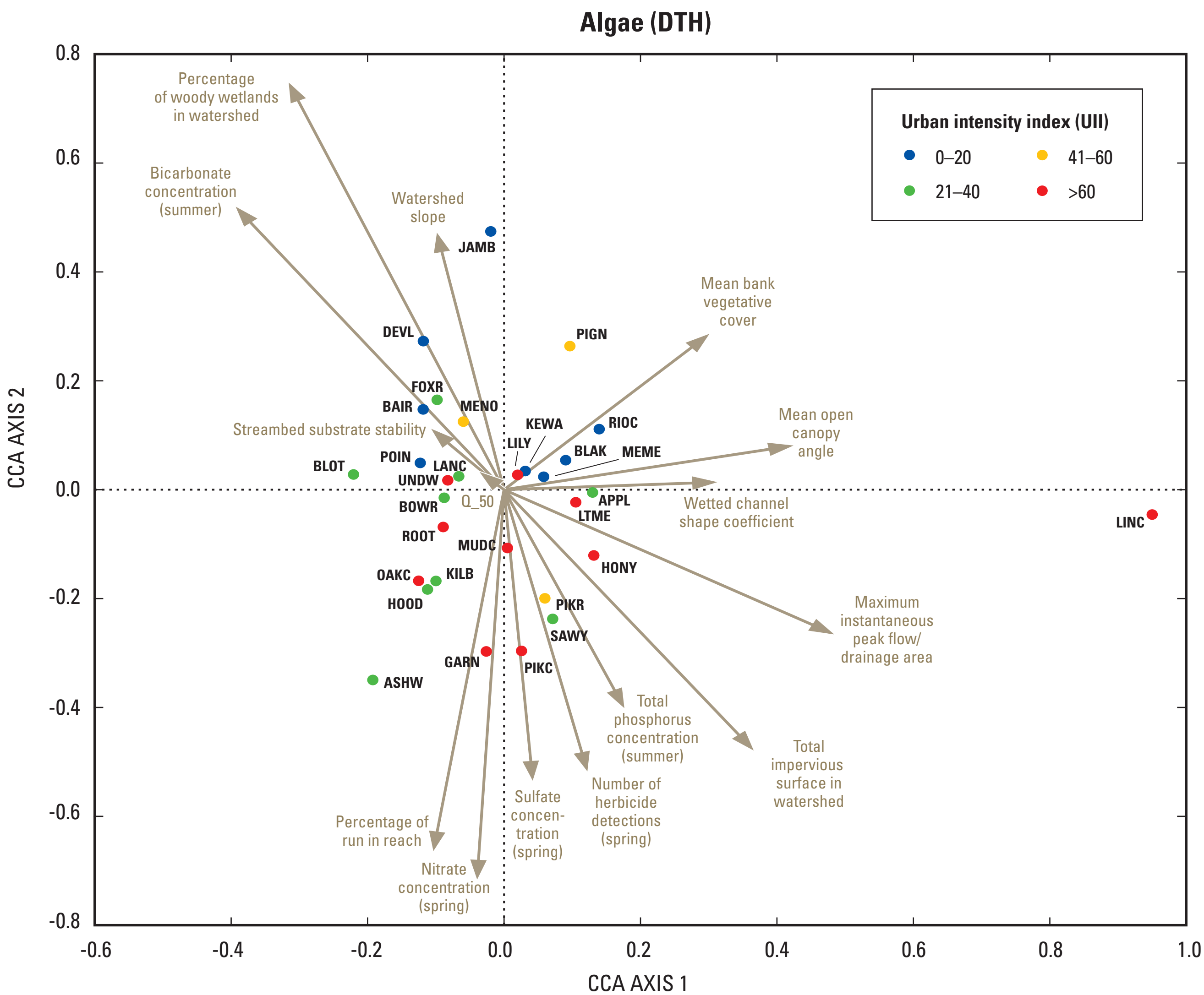


Figure 32. Relations of representative environmental characteristics to depositional-targeted habitat (DTH) algal assemblages for 30 study sites in the Milwaukee to Green Bay, Wis., study area.

The CCA ordinations showed that a subset of the environmental characteristics relating to DTH algal assemblages was related to RTH algal assemblages. For RTH algae with all sites included (fig. 33), the most important characteristics were woody wetlands in the watershed, total phosphorus concentration, sulfate concentration, total impervious surface in the watershed, open canopy angle, bicarbonate concentration, nitrate concentration, maximum instantaneous peak flow normalized by drainage area, mean bank vegetative cover, mean watershed slope, streambed substrate stability, and the discharge exceeded 50 percent of the time. Eigenvalues for axes 1 through 4 were 0.467, 0.193, 0.129, and 0.128, respectively; Monte Carlo permutations tests showed that all axes were significant. Without Lincoln Creek, however, the eigenvalue for axis 1 dropped to 0.191 ($p < 0.05$); open canopy angle became less important than total impervious surface and mean bank vegetative cover; maximum instantaneous peak flow normalized by drainage area dropped in importance for RTH algae. In summary, DTH and RTH algal assemblages related most to a similar suite of environmental characteristics.

Invertebrates

A total of 269 invertebrate taxa were identified at the 30 sites. The greatest number of taxa (taxa richness) at a site for RTH samples and for combined RTH/QMH samples was found at the least urban site, Jambo Creek, with 53 (RICH) and 85 (RICH_qq) taxa, respectively (table 17). The greatest invertebrate abundance in RTH samples was found at a site with low urban intensity, Meeme River (UII = 6.96). The relative abundance and distribution of invertebrates was correlated to latitude (appendix 5), and this may have lessened our ability to discern relations between invertebrates and urbanization in this study. The most commonly identified macroinvertebrates were the isopod *Caecidotea* sp. (28 sites), the midge *Polypedilum* sp. (27 sites), the mayfly *Baetis flavistriga* McDunnough (26 sites), the caddisfly *Cheumatopsyche* sp. (25 sites), and oligochaete worms in the family Tubificidae (25 sites). The most-abundant taxa, relative to the mean percentage of a sample, also were *Caecidotea* sp. (16.2 percent), *Baetis flavistriga* McDunnough (10.1 percent), and *Cheumatopsyche* sp. (12.3 percent), as well as caddisflies in the *Hydropsyche depravata* group (5.6 percent). Most taxa were found at two or fewer sites and with abundances of less than 1 percent. Non-insects such as isopods and Tubificidae oligochaete worms are considered to be highly tolerant of degraded water-quality conditions, and the mayflies and caddisflies listed above are known to be relatively tolerant (Barbour and others, 1999).

Indicators of healthy invertebrate assemblages showed negative correlations to physical, chemical, and hydrologic characteristics of urbanization in this study. With increasing UII values, RTH invertebrate taxa richness (RICH, fig. 34*A*), Coleoptera taxa richness (COLEOPR, includes riffle beetles), scraper abundance and taxa richness (SC_abund, SC_rich), gatherer-collector taxa richness (GC_rich), and shredder taxa richness (SH_rich) decreased ($rho < -0.47$, $p < 0.01$; appendix 5). This was reflected in similar relations between these biotic metrics and increasing watershed population density (POPDEN00), percentage of watershed area in developed urban land, weighted by distance from the sample reach (especially pwNLCD01_24, fig. 34*B*-*D*), total impervious surface in the watershed and 100-m riparian zone (NLCD_IS) (NLCD_BIS), and road length in the watershed (RDLENGTH). In contrast, percentages of non-insect and isopod taxa (NONINSRp, ISOPRp) and the pollution-tolerance value based on richness (RICHTOL) increased in relation to these urban indicators (fig. 34*E*, *F*; appendix 5); however, RICHTOL relations were not always statistically significant. Decreasing mean bank vegetative cover (BankVegCovPct) and increasing mean bank erosion length (ErosionLengthAvg) were strongly related to a decrease in overall invertebrate abundance (ABUND) in this study (fig. 35).

Chloride, a chemical found in this study to increase with the UII, appeared to be a significant negative influence on benthic-invertebrate assemblages (fig. 36 *A*, *B*, *C*; appendix 5). Coleoptera taxa richness (COLEOPR) decreased with increasing spring chloride concentration (CHLOR); EPT (Ephemeroptera-Plecoptera-Trichoptera; mayfly-stonefly-caddisfly) abundance and overall invertebrate abundance decreased with increasing summer chloride concentration. The number of Ephemeroptera individuals (EPEM) decreased with increasing total pesticide concentration and with increasing Pesticide Toxicity Indexes for invertebrates and cladocerans; the percentage of isopod taxa (ISOPRp) increased. The percentage of EPT taxa (EPTRp) correlated in similar but weaker fashion when compared to EPEM.

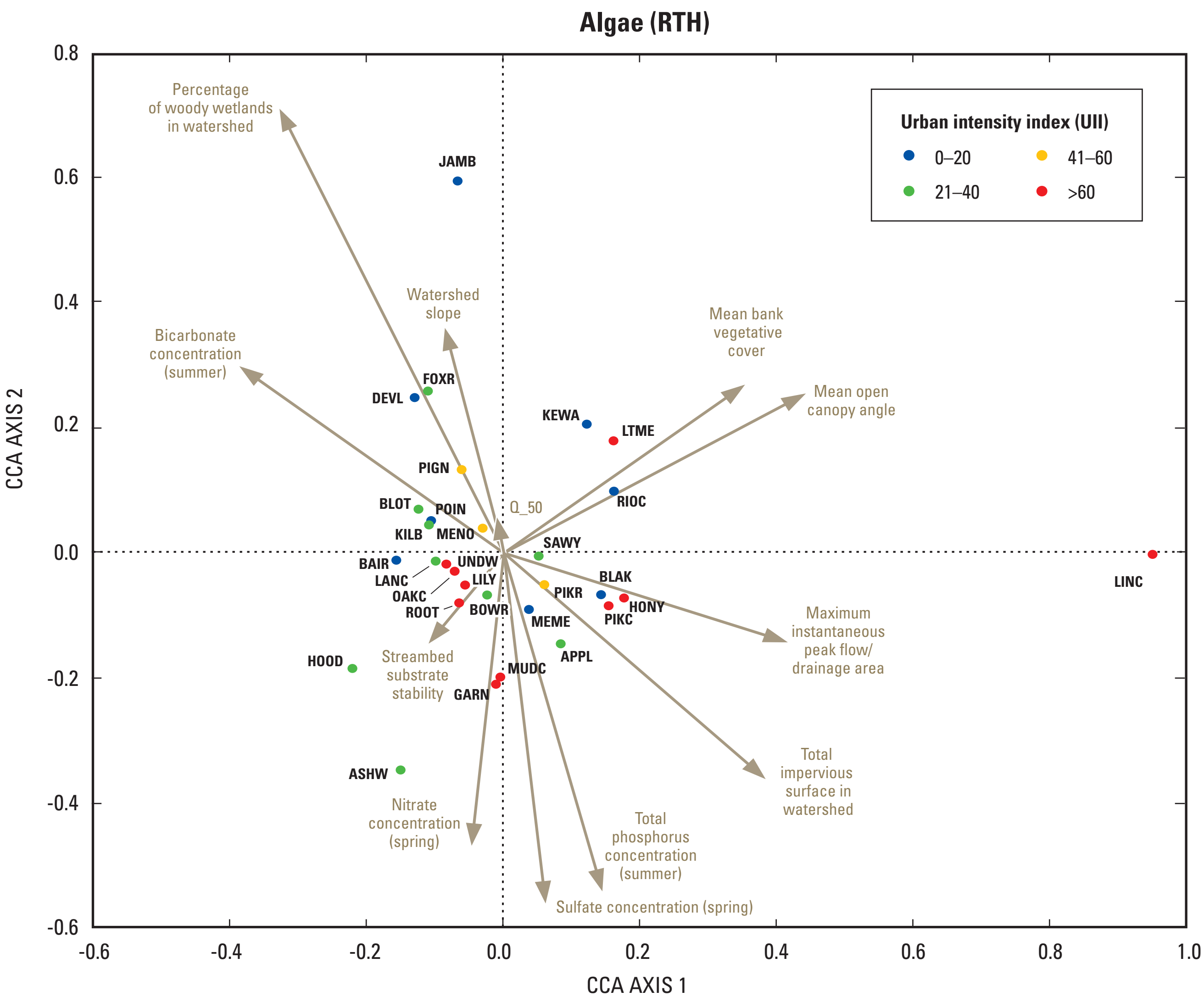


Figure 33. Relations of representative environmental characteristics to richest-targeted habitat (RTH) algal assemblages for 30 study sites in the Milwaukee to Green Bay, Wis., study area.

Table 17. Biological metrics computed from benthic-macroinvertebrate assemblages for 30 sites in the Milwaukee to Green Bay, Wis., study area.

[Site list is sorted by urban intensity index (UII) values, from lowest to highest. All metrics shown were computed from semi-quantitative richest-targeted habitat, except RICH_qq and NONINSRp_qq which were computed from combined richest-targeted habitat and qualitative-multihabitat samples. Site abbreviations are listed in table 1. Metric definitions are listed in appendix 1-9.]

Site abbreviation	RICH_qq	RICH	RichTOL	ABUND	ABUNDTOL	BIVAL	CHp	CHR	COLEOPp	COLEOPR	DIP	DIPRp	EPEM	EPEMp	EPEMR
JAMB	85	53	4.5	14,520	4.5	0	37	17	8	6	6,935	45	2,203	15	5
BLAK	41	19	6.3	9,007	6.7	54	52	7	0	1	4,786	47	0	0	0
MEME	78	37	5.4	53,007	5.5	1,186	19	8	9	4	11,347	27	3,048	6	3
RIOC	83	39	5.7	35,195	5.6	95	36	11	11	4	12,986	36	1,224	3	4
DEVL	72	43	4.6	4,732	3.6	0	11	10	7	4	582	30	2,663	56	7
KEWA	81	34	6.2	29,833	7.2	470	9	7	3	5	3,577	32	470	2	2
BAIR	50	31	5.5	8,258	4.7	0	29	11	7	3	2,546	45	743	9	2
POIN	51	25	4.9	11,197	4.5	161	2	5	29	3	322	28	1,516	14	2
ASHW	41	30	6.1	3,935	7.8	79	14	9	2	4	638	47	11	0	1
BLOT	49	25	6.2	18,697	5.7	1,468	14	3	6	3	2,937	20	226	1	1
KILB	55	39	6.1	5,884	6.3	64	71	18	2	4	4,175	49	81	1	2
HOOD	47	31	5.9	4,162	5.3	98	14	11	10	2	901	45	274	7	3
SAWY	62	28	6.1	6,396	6.7	403	3	6	3	3	403	36	40	1	1
APPL	45	17	5.8	9,746	6.3	33	2	3	11	2	614	29	678	7	1
LANC	47	28	4.7	5,563	5.0	34	1	3	12	3	322	25	306	6	3
BOWR	53	32	5.9	4,934	5.6	0	19	11	7	5	1,016	47	781	16	3
FOXR	71	27	5.0	10,388	4.8	322	5	4	8	2	936	26	3,742	36	3
MENO	57	21	5.0	2,551	4.8	17	3	2	15	2	94	19	1,513	59	3
PIGN	57	25	5.4	4,854	5.8	1	4	7	18	2	369	36	710	15	2
PIKR	39	25	5.5	7,118	5.2	0	17	9	15	2	1,491	44	2,379	33	3
GARN	45	26	5.9	8,046	5.1	29	4	6	6	1	1,318	31	1,427	18	2
LILY	55	32	5.7	10,871	5.8	65	5	9	12	4	708	34	1,418	13	2
MUDC	58	33	5.8	6,264	5.3	203	13	7	1	2	970	30	324	5	2
LTME	43	23	5.8	3,248	5.9	134	3	5	1	2	112	26	1,680	52	4
UNDW	52	30	5.8	4,661	5.8	114	30	8	5	3	1,612	40	1,129	24	1
OAKC	50	22	6.0	13,188	5.4	40	7	6	5	1	1,128	36	363	3	1
PIKC	29	16	6.6	8,847	6.6	27	18	6	0	0	1,883	44	0	0	0
HONY	36	25	6.7	1,181	6.5	0	11	6	0	1	158	36	240	20	1
ROOT	50	30	6.3	3,607	6.5	11	21	12	0	0	1,008	47	1,019	28	1
LINC	38	23	6.1	13,109	6.3	40	30	5	0	0	3,990	26	806	6	2

Table 17. Biological metrics computed from benthic-macroinvertebrate assemblages for 30 sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[Site list is sorted by urban intensity index (UII) values, from lowest to highest. All metrics shown were computed from semi-quantitative richest-targeted habitat, except RICH_qq and NONINSRp_qq which were computed from combined richest-targeted habitat and qualitative-multihabitat samples. Site abbreviations are listed in table 1. Metric definitions are listed in appendix 1-9.]

Site abbreviation	EPT	EPTp	EPTRp	EPT_CHRp	GASTRORp	ISOPRp	MOLCRU	MOLCRUR	NCHDIPR	NONINSR	NONINSRp	NONINSRp_qq	ODIPNIR	OLIGO	TANY
JAMB	5,054	35	30	0.9	4	0	162	3	7	5	9	14	12	538	1,642.0
BLAK	27	0	5	.1	16	5	3,898	5	2	8	42	41	10	215	4,240.5
MEME	14,902	28	24	1.1	5	3	19,816	7	2	12	32	28	14	339	4,662.6
RIOC	10,631	30	23	.8	8	3	6,402	7	3	10	26	18	13	377	4,893.3
DEVL	3,600	76	37	1.6	0	2	50	3	3	5	12	14	8	48	177.6
KEWA	2,634	9	12	.6	3	3	21,453	5	4	11	32	20	15	378	602.6
BAIR	4,581	55	23	.6	6	3	389	4	3	6	19	20	9	65	160.8
POIN	7,128	64	32	1.6	0	0	166	2	2	6	24	22	8	129	32.0
ASHW	56	1	10	.3	7	3	1,727	6	5	8	27	24	13	1,411	22.9
BLOT	6,778	36	16	1.3	4	4	4,294	6	2	11	44	39	13	1,298	.0
KILB	370	6	13	.3	10	3	629	6	1	10	26	24	11	499	761.5
HOOD	2,386	57	16	.5	3	3	214	5	3	8	26	21	11	145	54.0
SAWY	1,127	18	14	.7	4	4	4,198	5	4	10	36	24	14	142	.0
APPL	2,710	28	24	1.3	12	6	5,258	4	2	6	35	24	8	98	40.0
LANC	2,596	47	25	2.3	0	4	1,712	5	4	8	29	23	12	113	.0
BOWR	2,444	50	16	.5	6	3	1,066	3	3	5	16	19	8	32	181.0
FOXR	7,097	68	37	2.5	0	4	1,387	5	3	8	30	23	11	0	.0
MENO	1,901	75	38	4.0	0	5	118	3	2	6	29	28	8	0	.0
PIGN	1,516	31	20	.7	0	4	1,986	4	2	7	28	26	9	0	16.0
PIKR	4,072	57	20	.6	0	4	42	2	2	6	24	18	8	61	40.0
GARN	4,761	59	19	.8	8	4	1,186	7	2	10	38	29	12	162	134.4
LILY	2,838	26	19	.7	3	3	3,582	5	2	9	28	24	11	129	64.0
MUDC	3,893	62	18	.9	9	3	774	9	3	14	42	33	17	242	66.6
LTME	1,848	57	26	1.2	0	4	1,042	4	1	8	35	35	9	134	11.2
UNDW	1,516	33	13	.5	7	3	888	5	4	9	30	27	13	274	829.3
OAKC	9,722	74	23	.8	5	5	161	4	2	6	27	24	8	1,008	300.2
PIKC	0	0	0	.0	0	6	3,952	2	1	7	44	34	8	806	27.2
HONY	346	29	16	.7	8	4	600	5	2	10	40	33	12	24	14.4
ROOT	1,198	33	17	.4	7	3	314	4	2	9	30	36	11	806	112.7
LINC	4,394	34	22	1.0	17	4	2,986	7	1	12	52	42	13	928	2,737.1

Table 17. Biological metrics computed from benthic-macroinvertebrate assemblages for 30 sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[Site list is sorted by urban intensity index (UII) values, from lowest to highest. All metrics shown were computed from semi-quantitative richest-targeted habitat, except RICH_qq and NONINSRp_qq which were computed from combined richest-targeted habitat and qualitative-multihabitat samples. Site abbreviations are listed in table 1. Metric definitions are listed in appendix 1-9.]

Site abbreviation	TANYp	TRICHR	FC_abund	pFC_rich	GC_rich	pGC_rich	pOM_rich	PR_rich	SC_abund	SC_rich	SH_rich	Margalef
JAMB	11.3	9	3,514	21	16	31	4	12	1,666	8	3	12
BLAK	47.1	1	300	16	7	37	0	2	3,817	3	4	5
MEME	8.8	6	13,264	22	9	24	11	6	7,789	6	3	8
RIOC	13.9	5	12,019	15	14	36	3	5	6,361	8	4	8
DEVL	3.8	7	921	14	12	28	7	10	1,774	8	3	11
KEWA	2.0	2	3,143	15	11	33	3	8	2,070	4	4	7
BAIR	1.9	5	3,547	23	10	32	0	4	1,486	6	4	8
POIN	.3	6	5,708	24	6	24	8	4	1,955	5	2	6
ASHW	.6	2	67	13	12	40	3	8	113	3	2	8
BLOT	.0	3	8,075	21	8	33	4	7	2	1	1	6
KILB	12.9	3	719	18	14	36	3	5	737	9	2	10
HOOD	1.3	2	2,522	19	10	32	13	5	32	2	3	8
SAWY	.0	3	1,068	14	11	39	4	6	706	3	3	7
APPL	.4	3	2,169	24	6	35	0	0	1,905	4	3	4
LANC	.0	4	2,225	14	8	29	7	8	735	4	2	7
BOWR	3.7	2	1,976	19	7	23	3	8	1,230	4	5	8
FOXR	.0	7	4,244	30	5	19	15	5	354	2	3	6
MENO	.0	5	397	29	5	24	10	4	85	3	0	6
PIGN	.3	3	919	24	6	24	12	8	484	1	1	7
PIKR	.6	2	2,035	24	6	24	8	5	342	2	3	6
GARN	1.7	3	4,247	12	8	32	12	5	780	3	2	6
LILY	.6	4	775	22	8	25	6	8	1,806	3	3	8
MUDC	1.1	4	3,854	21	10	30	6	6	325	6	2	8
LTME	.3	2	325	22	5	22	17	6	11	1	2	6
UNDW	17.8	3	1,375	23	8	27	0	7	871	5	2	8
OAKC	2.3	4	9,279	23	6	27	9	3	242	2	3	5
PIKC	.3	0	323	19	5	31	0	6	0	0	2	4
HONY	1.2	3	139	25	10	42	0	4	43	2	2	8
ROOT	3.1	4	430	23	11	37	3	5	101	3	2	8
LINC	20.9	3	3,224	17	6	26	4	5	968	5	2	5

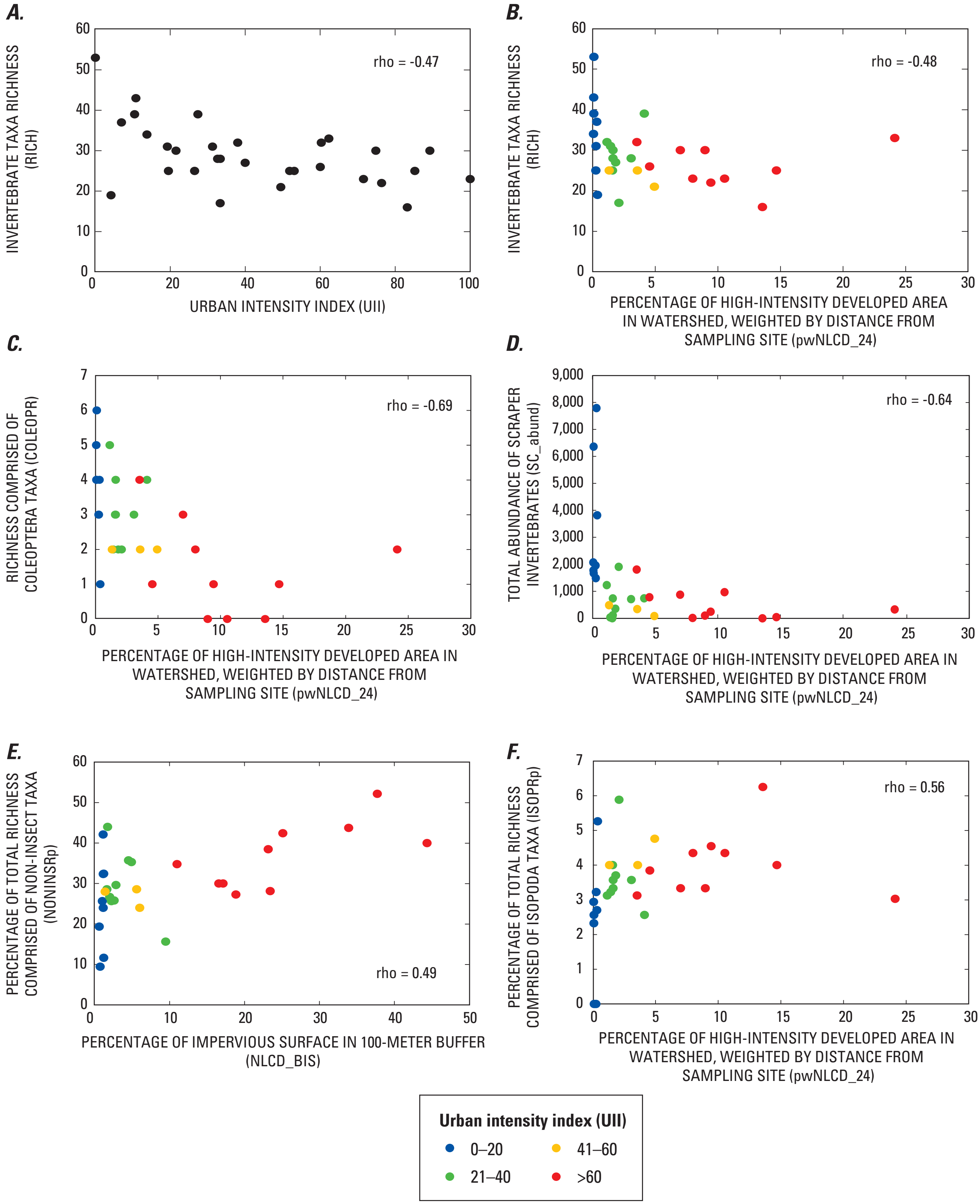


Figure 34. Relations between benthic-invertebrate metrics and land-cover-derived urban metrics for 30 study sites in the Milwaukee to Green Bay, Wis., study area.

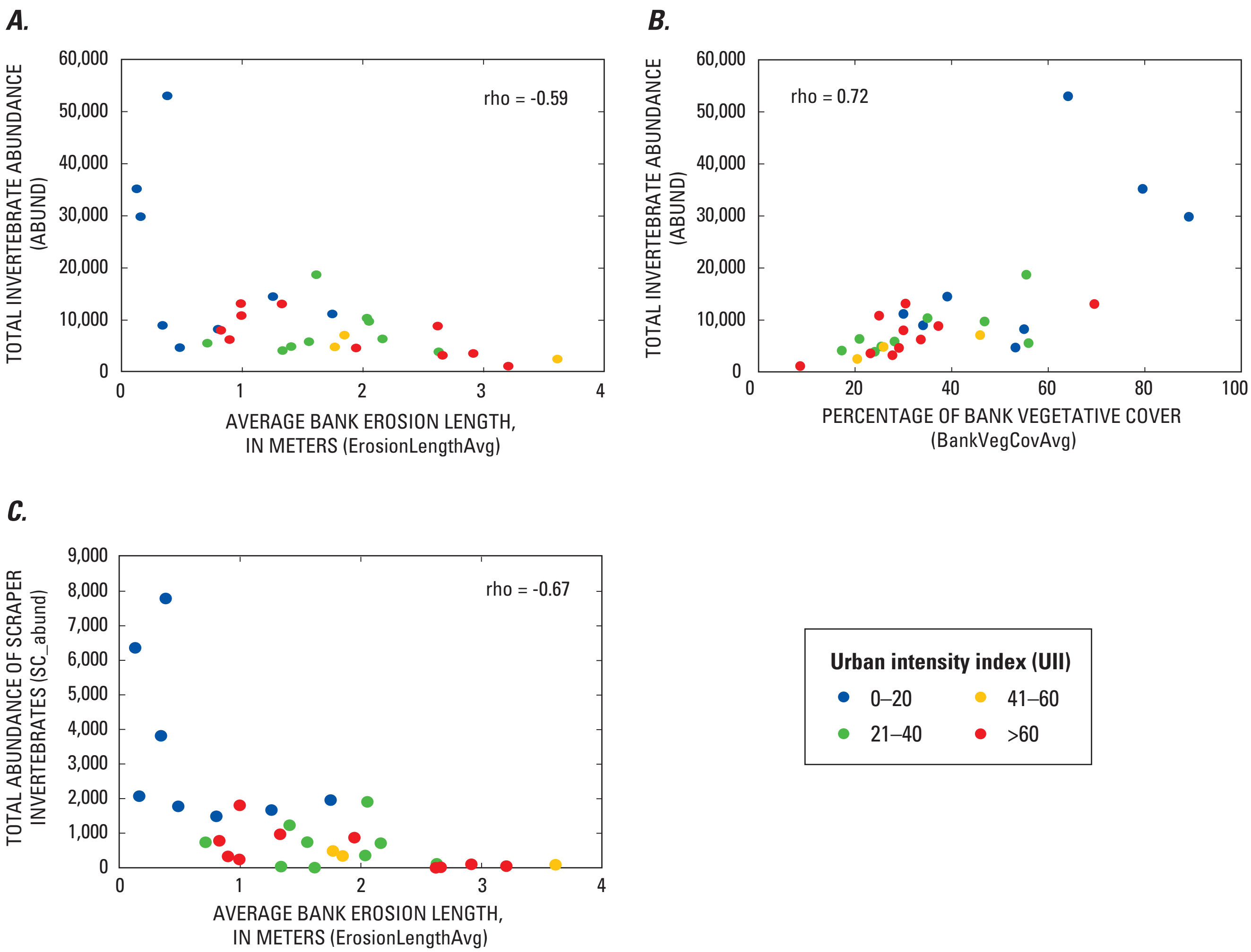


Figure 35. Relations between benthic-invertebrate metrics and instream-habitat metrics for 30 study sites in the Milwaukee to Green Bay, Wis., study area.

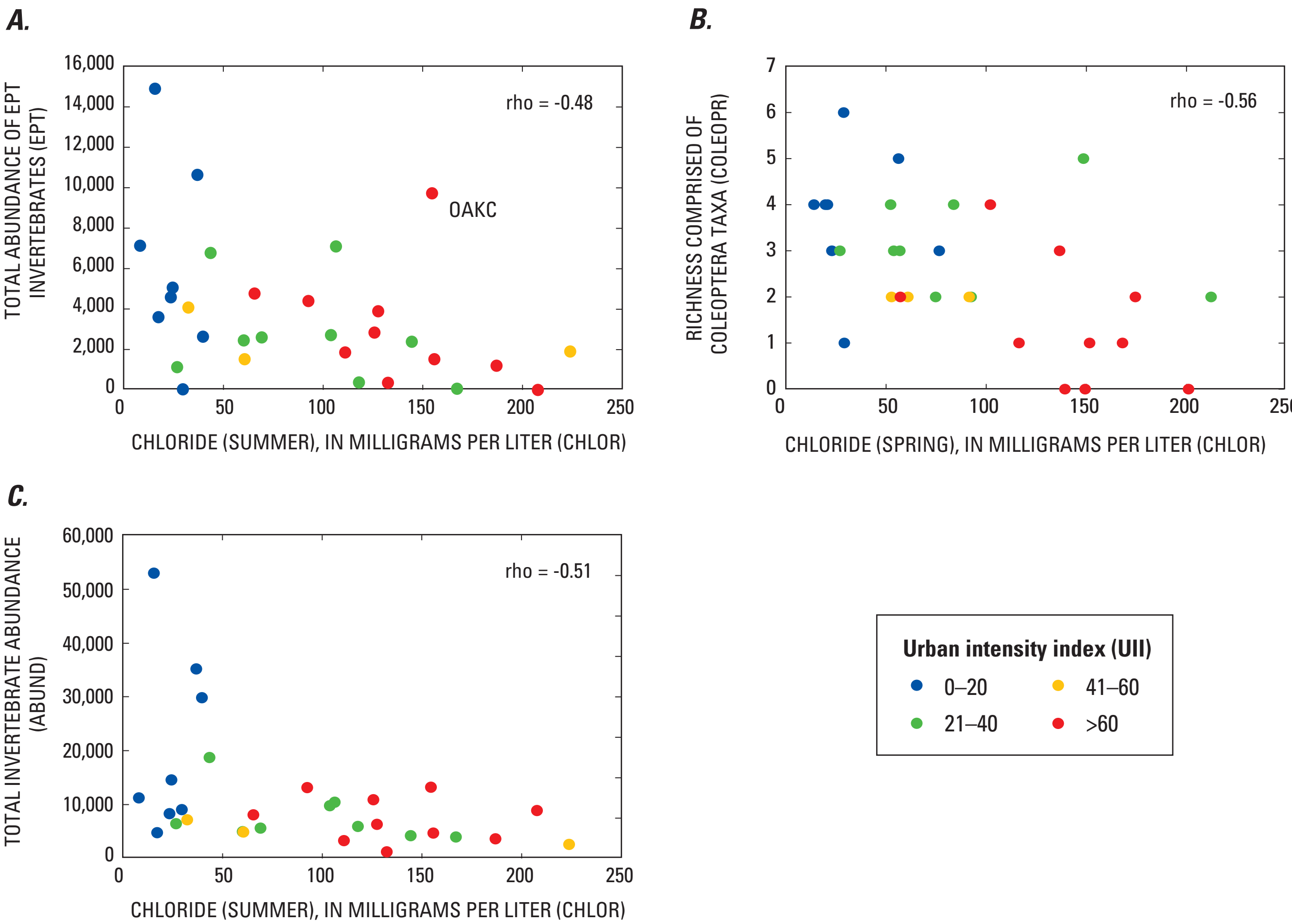
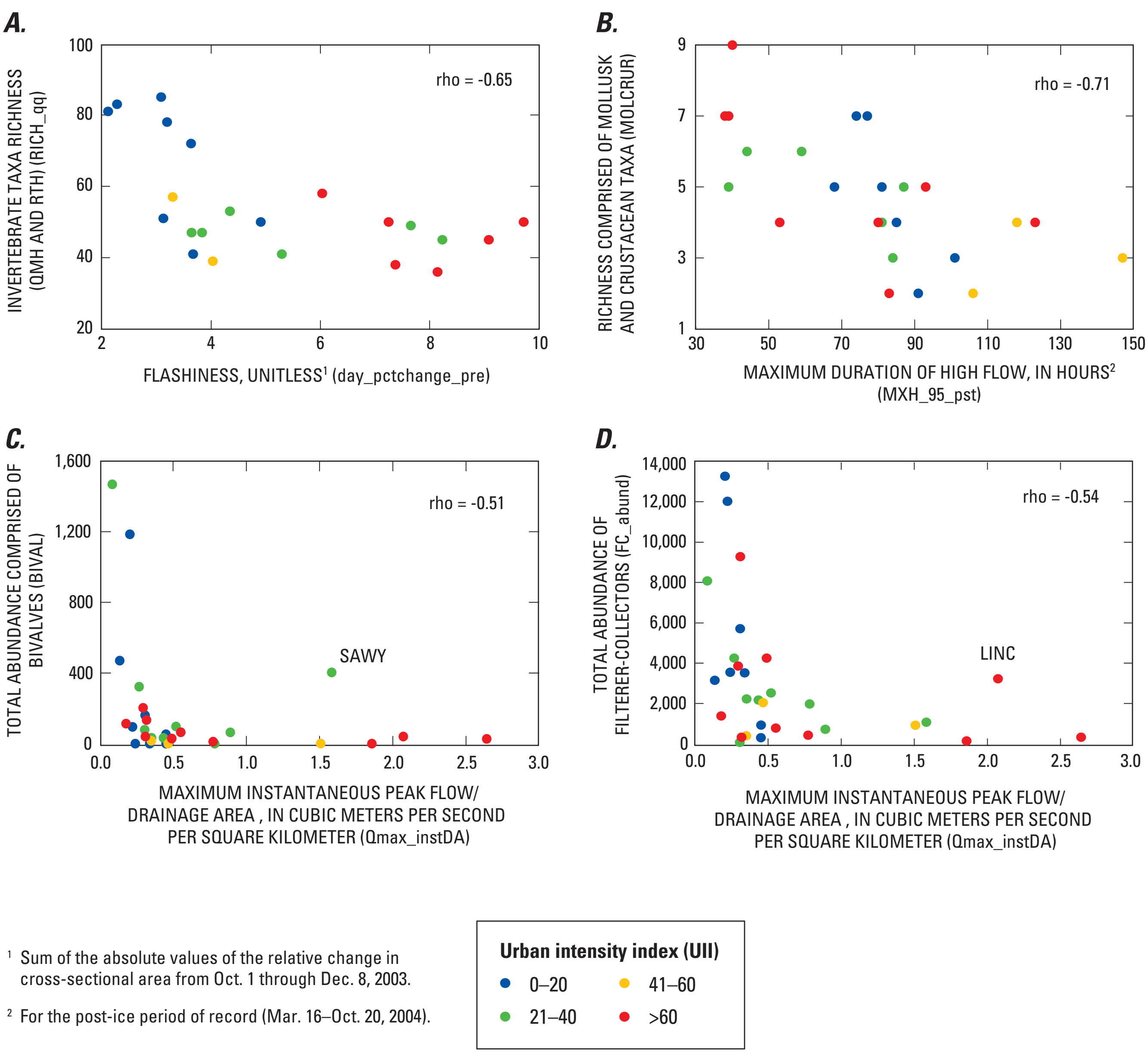


Figure 36. Relations between benthic-invertebrate metrics and chloride concentrations for 30 study sites in the Milwaukee to Green Bay, Wis., study area. Site abbreviations listed in table 1.

As might be expected, increasing detections and concentrations of selected chemicals found in SPMDs correlated to changes in invertebrate metrics indicating degraded assemblages (appendix 5). Invertebrate abundance (ABUND) and richness (RICH and RICH_qq), COLEOPR, richness of non-chironomid Diptera (NCHDIPR), caddisfly richness (TRICHR), SC_abund, SC_rich, and SH_rich decreased with increasing SPMD toxicity potential (TEQ, UPAH) and concentrations of pentachloroanisole and the PAHs fluoranthene, phenanthrene, and pyrene; non-insect taxa for RTH and QMH samples combined (NONINSRp_qq) and ISOPRp increased.

Invertebrate assemblages related strongly to hydrologic conditions indicative of urban streams (appendix 5-2). Increased daily stream flashiness (day_pctchange) during the pre-ice period correlated to decreased RICH_qq, with declines in richness of about 50 percent associated with a doubling of daily stream flashiness from 2 to 4 (fig. 37*A*). There were about twice as many significant correlations ($p<0.01$) to invertebrate metrics for annual-streamflow metrics and post-ice-hydrology metrics compared to pre-ice-hydrology metrics (table 8; appendix 5-2). Post-ice-hydrology metrics encompassed high flows associated with spring snowmelt and high-intensity thunderstorms on wet soil—conditions conducive to high flow peaks. Higher invertebrate correlations during the post-ice period (March–October) may be indicative of invertebrate response to flashiness (day_pctchange), high-flow magnitude (pct_99n) and duration of high (MXH_95) and low (MXL_5) flows (table 8; appendix 5-2). The strong negative correlation between the maximum duration of high flow (MXH_95) and mollusk/crustacean taxa richness (MOLCRUR) may indicate that these bivalve/crustacean taxa were washed out after extended periods of high flows (fig. 37*B*). In general, the number of bivalve individuals (BIVAL) and number of filterer-collector individuals (FC_abund) decreased as peak flows (Qmax_instDA) increased; they remained low when peak flows exceeded approximately 0.5 m^3/km^2 (fig. 37*C*, *D*). The Qmax_instDA metric is an approximate surrogate for maximum shear stress on the stream bottom; therefore these data support the concept that certain invertebrates can withstand a limited amount of shear stress (Strayer, 1999; Gjerlov and others, 2003) while others cannot. Predator invertebrate taxa richness (PR_rich) decreased as the high-flow Q10 increased (fig. 37*E*).

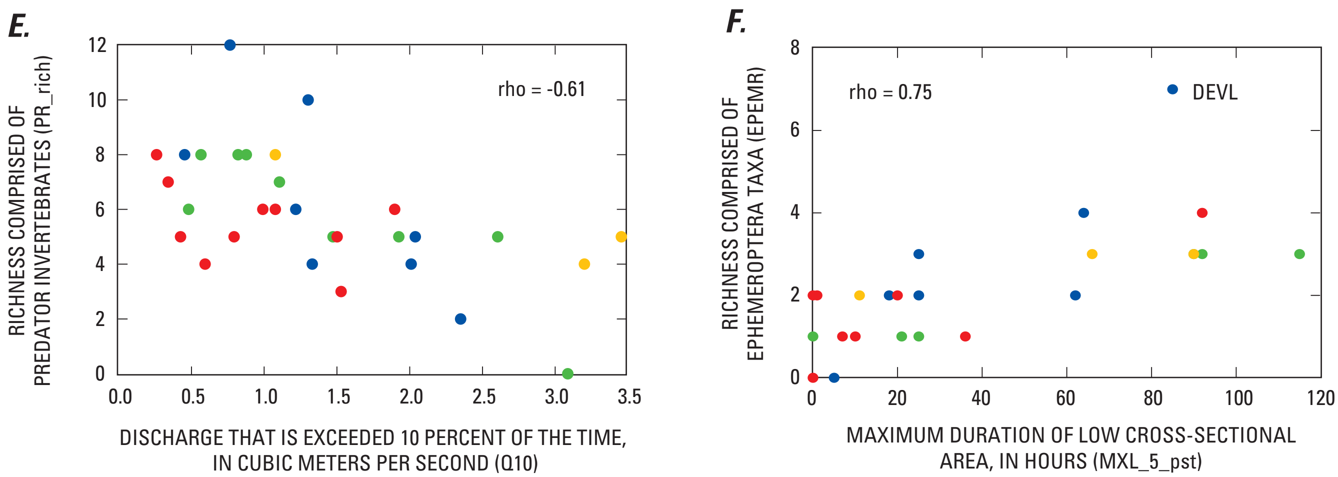
For the adjoining Upper Illinois River Basin, Harris and others (2005) found significant negative relations between urban land in the watershed and overall invertebrate taxa richness, as well as EPT abundance and macroinvertebrate diversity; whereas, a significant positive relation was seen between developed urban land and the pollution-tolerance value based on richness (RICHTOL). In the Wisconsin study, the suite of EPT metrics showed few significant relations to the UII or to other GIS-derived urban-associated characteristics. EPT metrics, notably mayfly taxa richness (EPEMR), the percentage of the total invertebrate abundance made up of EPT individuals (EPTp), and the percentage of EPT taxa (EPTRp) showed strong relations to hydrologic characteristics. Mayfly taxa richness (EPEMR) increased with the maximum duration of low flow (MXL_5) during the post-ice period (fig. 37*F*) and decreased with increasing flashiness (day_pctchange) and increasing high flows (pct_99n) in the post-ice period (fig. 37*G*; appendix 5). As base flow (Q90) increased, indicators of healthy invertebrate assemblages such as the percentage of EPT taxa (EPTRp) and ratio of EPT to chironomid midge richness (EPT_CHRp) increased (fig. 37*H*, *I*); indicators of degraded invertebrate assemblages such as the abundance of pollution-tolerant invertebrates (AbundTOL) and percentage of Dipteran taxa (DIPRp) decreased (fig. 37*J*, *K*; appendix 5). The Pike River base flow outlier may be a result of an overall wet year, including a greater than 30-percent increase in base flow for water year 2004 (table 5). The percentage of Tanytarsini midge individuals (TANYp) was high at sites with high base flow (fig. 37*L*). Diptera abundance (DIP) decreased as the maximum duration of low flows (MXL_25) in the pre-ice period increased; abundance became uniformly low when pre-ice low-flow periods were greater than 150 hours (fig. 37*M*). A possible indicator of a positive relation with small hydrologic disturbances, Margalef diversity (Margalef) increased with increasing small hydrograph changes (periodf1) during the post-ice period (fig. 37*N*).

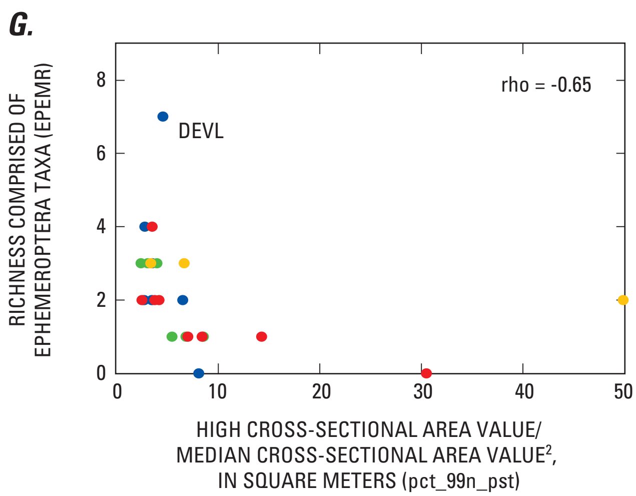


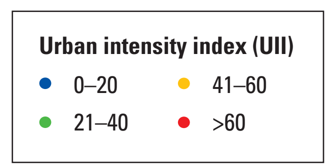
[1] Sum of the absolute values of the relative change in cross-sectional area from Oct. 1 through Dec. 8, 2003.

[2] For the post-ice period of record (Mar. 16–Oct. 20, 2004).

Figure 37. Relations between benthic-invertebrate metrics and hydrologic metrics for 30 study sites in the Milwaukee to Green Bay, Wis., study area.







[1] Maximum duration of low (5th percentile) cross-sectional area for post-ice period of record (Mar. 16–Oct. 20, 2004).

[2] High cross-sectional area value (99th percentile)/median cross-sectional area value for post-ice period of record (Mar. 16–Oct. 20, 2004).

Figure 37.—Continued

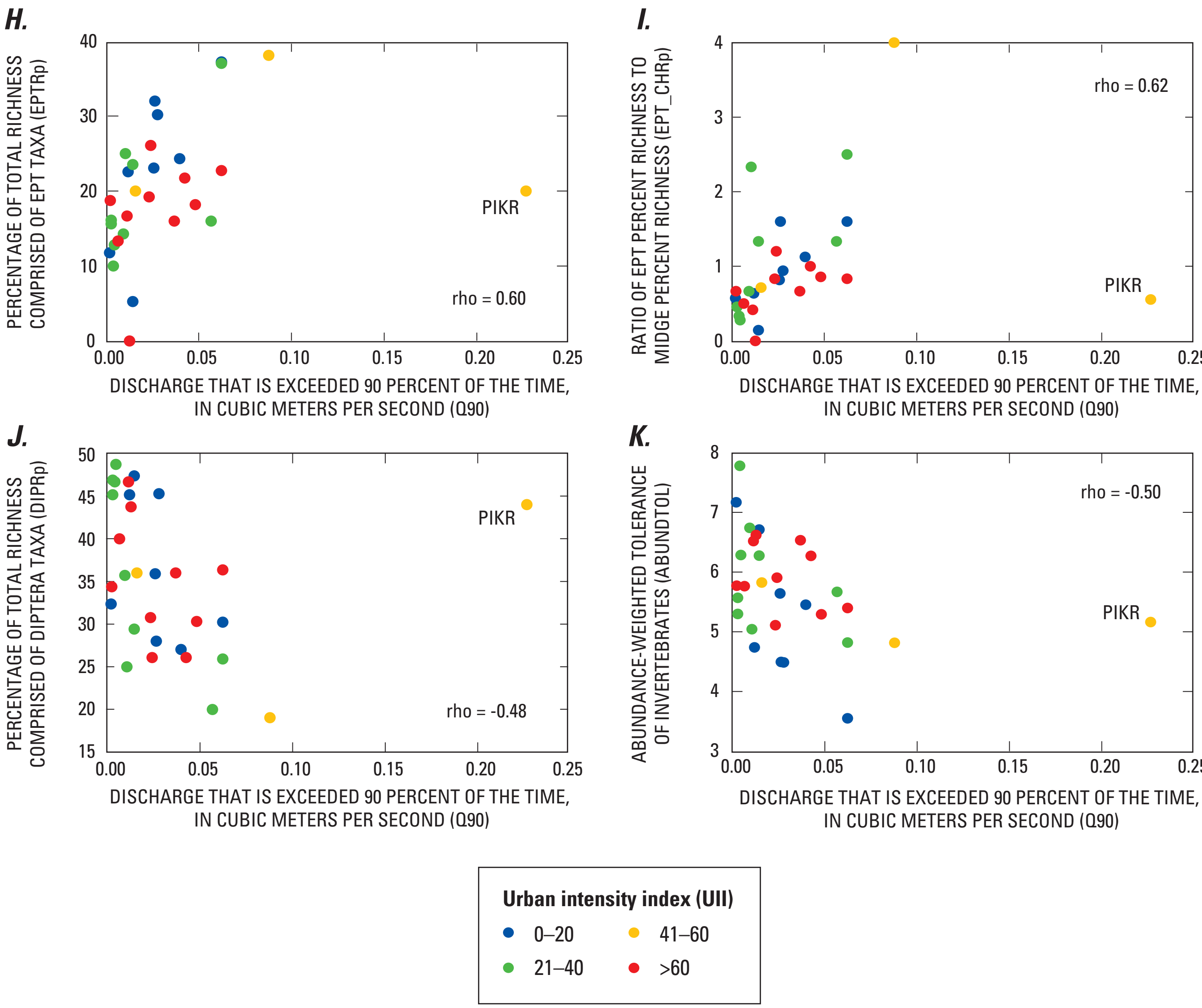
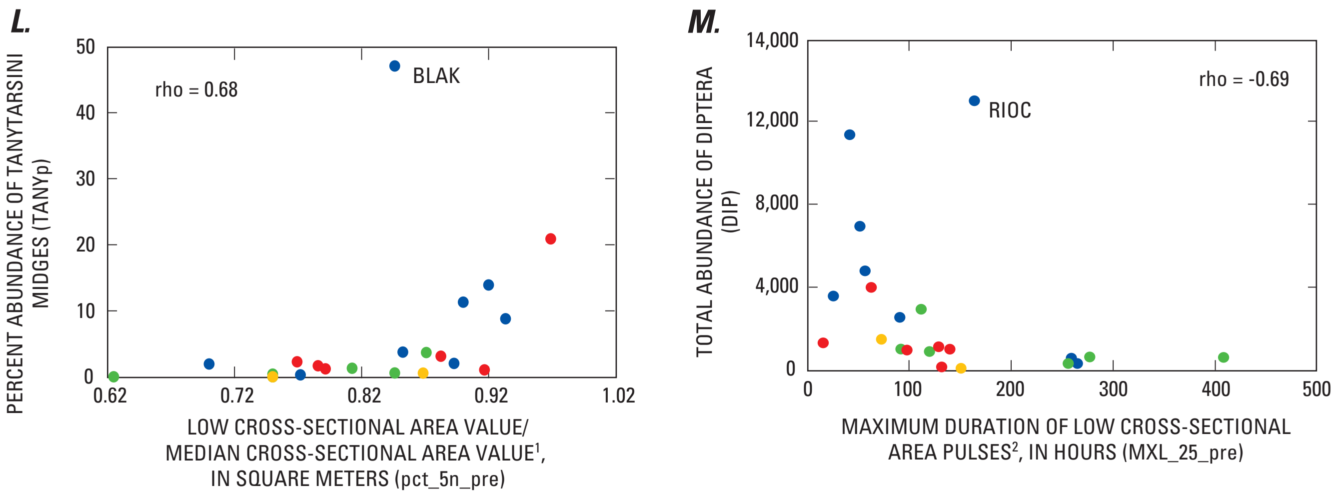
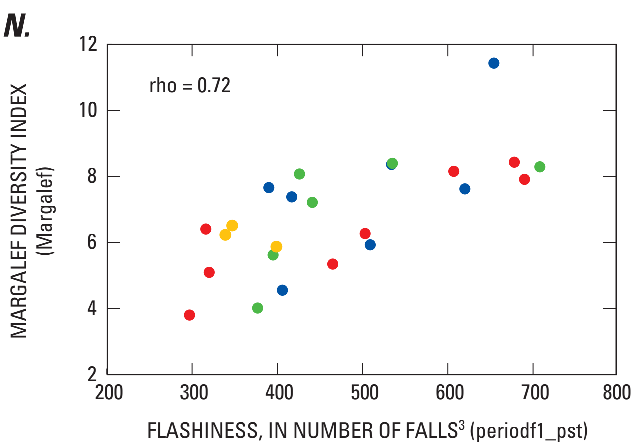
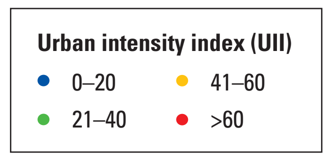


Figure 37.—Continued







[1] Low cross-sectional area value (5th percentile)/median cross-sectional area value for pre-ice period of record (Oct. 1–Dec. 8, 2003).

[2] Maximum duration of low (25th percentile) cross-sectional area pulses for pre-ice period of record (Oct. 1–Dec. 8, 2003).

[3] When total fall of cross-sectional area is greater than or equal to 1 times the median total fall over the post-ice period of record (Mar. 16–Oct. 20, 2004).

Figure 37.—Continued

CCA results indicated that variation in invertebrate assemblages among sites was most related to hydrologic, habitat, and chemical characteristics (fig. 38). As indicated by the relative length of the arrows in the CCA ordination, the most important environmental characteristics to invertebrates were instantaneous discharge (spring), discharge exceeded 50 percent of the time normalized by drainage area, total pesticide concentration (summer), dissolved nitrite concentration (summer), average bankfull-channel width-to-depth ratio, latitude, total impervious surface in the watershed, herbaceous upland natural/semi-natural vegetation in the 100-m riparian zone, Richards-Baker flashiness index, percentage of riffles in the reach, Froude number, water temperature (spring), and streambed-substrate stability. As noted earlier, total impervious surface was used in multivariate analyses as a representative for chloride, medium to high-intensity developed land, and road indices. Eigenvalues for axes 1 through 4 were 0.358, 0.235, 0.207, and 0.141,

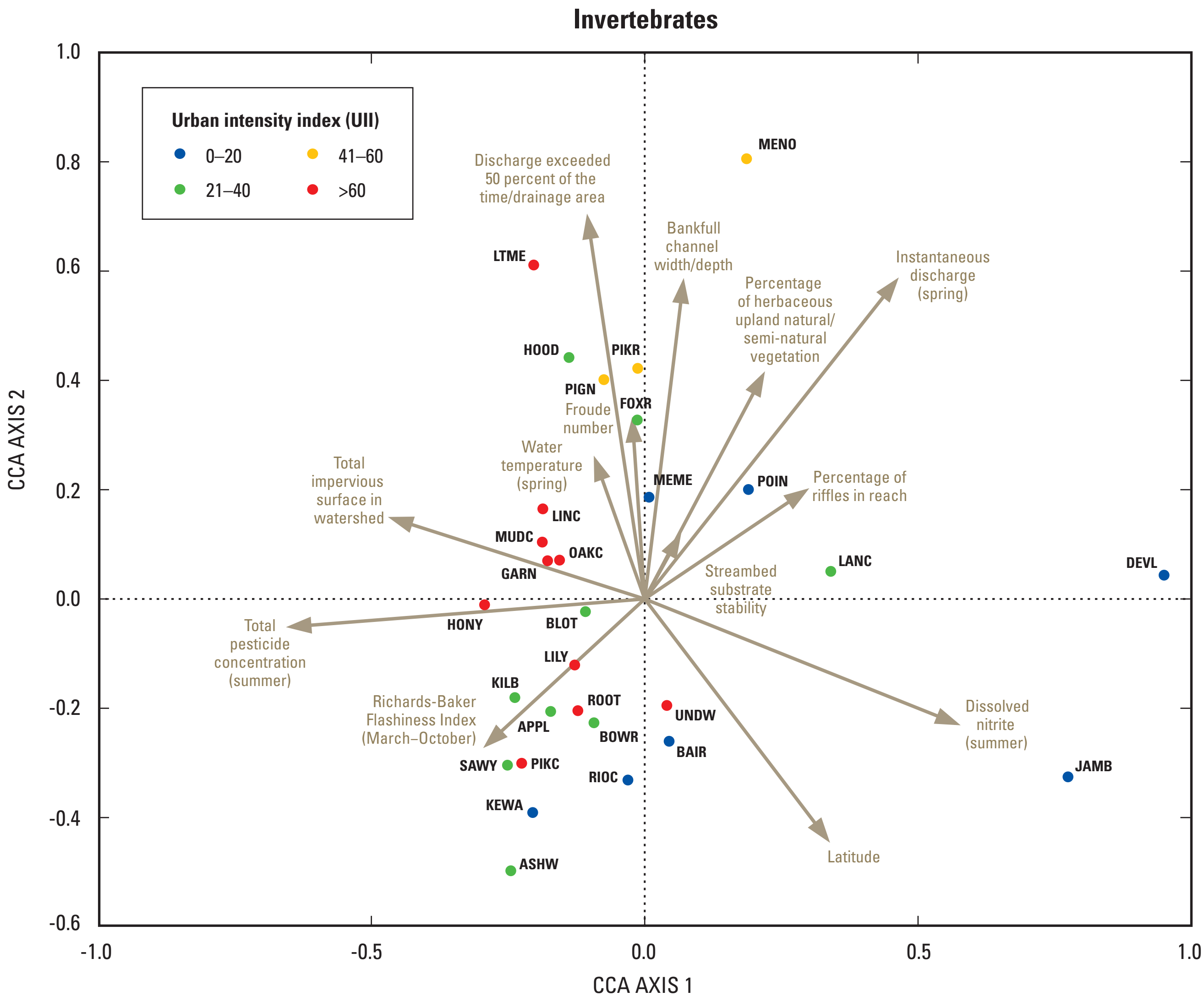


Figure 38. Relations of representative environmental characteristics to richest-targeted habitat (RTH) benthic macroinvertebrate assemblages for 30 study sites in the Milwaukee to Green Bay, Wis., study area.

respectively; Monte Carlo permutations tests showed that all axes were significant. The relatively low eigenvalues indicated that a large amount of the variation in the assemblages was not explained by the measured environmental characteristics; however, biological data are often noisy. An extreme outlier for invertebrate results, Black Creek, was excluded from final invertebrate CCA analyses. An unusually high flow (32 ft^3/s compared to an average flow of less than 1 ft^3/s), a couple months prior to sample collection, may have swept invertebrates downstream at Black Creek; however, high concentrations of insecticides found in stream water also may have contributed to the poor invertebrate assemblage. The poor invertebrate assemblage was in contrast to the "fair" fish IBI score from this primarily agricultural stream. In the CCA ordination plot, sites with UII values greater than 20 generally formed a separate group from sites with values less than 20; however, Lancaster Creek (UII value 33) grouped more closely with sites having UII values less than 20.

Fish

The fish assemblages at the 30 sites were made up of 56 fish species; 4 fish species were not native to Wisconsin. Common carp (*Cyprinus carpio*) was the most-abundant non-native fish. The other non-native fishes were salmonids that are commonly stocked in Wisconsin waters. White sucker (*Catostomus commersonii*, 27 sites), green sunfish (*Lepomis cyanellus*, 23 sites), creek chub (*Semotilus atromaculatus*, 25 sites), and central mudminnow (*Umbra limi*, 21 sites) were the most-common fish species found. The four common species are considered tolerant of degraded water-quality conditions (Barbour and others, 1999). The most abundant taxa (mean percentage of abundance) across sites were creek chub (14 percent), white sucker (13 percent), and green sunfish (9.8 percent). Fish intolerant of disturbance or pollution (INTOL_LY, SENSfshE) were absent from more than half the sampled sites and were low in abundance at most other sites. In contrast, tolerant fish were not only present at all sites but dominated assemblages at most sites (table 18). Biotic homogenization due to increasing numbers of tolerant urban-adapted taxa at the expense of intolerant endemic taxa is a concern in many urbanizing ecosystems (McKinney, 2006; Scott, 2006).

Variation in fish assemblages among sites correlated to physical and chemical changes associated with urbanization, as shown by relations between fish assemblages or metrics and environmental characteristics (table 18; appendix 6). Fish IBI scores computed according to Lyons (1992) or Lyons and others (1996) can range from "excellent" (100–65), "good" (64–50), "fair" (49–30), "poor" (29–20), to "very poor" (19–0). Overall IBI scores in this study were "fair" to "very poor" at all but two sites. Jambo Creek (UII value 0) scored at the lower end (54) of "good" biotic integrity. Jambo Creek was the only coldwater stream in this study; any comparison with warmwater IBI scores should be viewed with caution. Pigeon Creek, a moderately urban watershed, was the only site out of 30 with an "excellent" IBI score (72). This may have been in part the result of the proximity of the site to its confluence with the Milwaukee River (the river would serve as a source of increased fish diversity and abundance). In general, fish IBI scores, taxa number or richness, and the number of native taxa decreased with increasing UII (fig. 39*A*, *B*). The IBI scores for three sites (Pigeon Creek, Underwood Creek, and Root River) were higher than expected, based on their UII. The IBI at the Root River was primarily attributable to the dominance (90 percent) by the moderately tolerant brook stickleback (*Culaea inconstans*) and possibly was not representative of the overall fish assemblage for this stream. Spearman rank correlations with fish metrics were highest for the percentages of high- and medium-intensity developed land in the watershed or 100-m riparian zone (PNLCD_23, pwNLCD_23, PNLCD_24, pwNLCD_01, NLCD_S24), total impervious surface in the watershed and 100-m riparian zone (NLCD_IS, NLCD_BIS), ratio of developed open space to all developed land (PNLCD_21 divided by PNLCD1_2), forest and wetland (woody or herbaceous) in the 100-m riparian zone and watershed (forest: PNLCD_41, P_NLCD1_4, P_NLCD1_B4, pwNLCD_42, pwNLCD_43; wetland: P_NLCD1_B9, P_NLCD1_9, PNLCD_90, pwNLCD_90, pwNLCD_95), slope (SLOPE_X), riffles (GCUTypeRiffPct), pools (GCUTypePoolPct), coefficient of variation for the wetted channel shape index (ChShpCV), GCU Index, average bankfull depth excluding pools (BFDepthNoPools), and wetted width-to-depth ratio (WidthDepthAvg). The negative relation (rho = -0.51) between fish IBI and total impervious surface in the watershed (NLCD_IS) became stronger (rho = -0.59) if five sites with the highest agricultural land cover (Ashwaubenon Creek, Kewaunee River tributary, Baird Creek, Point Creek, Kilbourn Creek) were excluded (fig. 39*C*). The fish IBI and fish taxa richness (TAXAfish) showed strong increases (rho >0.7) with increases in the ratio of developed open space to all developed land (PNLCD_21 divided by PNLCD1_2) (fig. 40).

Table 18. Biological metrics computed from fish assemblages for 30 sites in the Milwaukee to Green Bay, Wis., study area..

[Site list is sorted by urban intensity index (UII) values, from lowest to highest. Metrics in columns C–J were computed based on Lyons (1992)[1]; metrics in columns K–P were based on Barbour and others (1999); metrics in columns Q–U were computed based on Goldstein and Meador (2004). Site abbreviations are listed in table 1. Metric definitions are in appendix 1-10.]

	A	B	C	D	E	F	G	H	I	J
Site abbreviation	TAXAfish	ABUNfish	IBI Score	NATIVE_LY	DARTER_LY	INTOLR_LY	TOLR_LY	OMNI_LY	INSC_LY	LITHO_LY
JAMB[1]	15	135	54	14	2	2	36	15	87	23
BLAK	13	1,144	30	13	1	1	428	33	250	763
MEME	15	695	47	14	2	1	230	13	638	212
RIOC	12	2,765	32	12	2	1	1,308	514	1,812	449
DEVL	16	410	35	15	1	1	173	31	264	123
KEWA	10	2,058	39	10	1	0	1,988	96	1,899	111
BAIR	10	921	24	10	1	1	586	53	393	297
POIN	16	424	37	16	1	2	248	50	180	98
ASHW	6	89	14	6	0	0	85	15	64	15
BLOT	8	193	47	8	0	0	26	8	75	101
KILB	7	8	5	6	1	0	6	2	4	2
HOOD	15	385	29	14	2	2	226	125	179	75
SAWY	7	37	2	7	0	0	29	24	11	19
APPL	9	322	15	8	1	0	291	232	57	209
LANC	8	253	34	8	2	0	54	11	206	103
BOWR	9	323	14	9	1	0	259	222	67	105
FOXR	24	1,040	47	23	4	1	839	41	959	82
MENO	13	296	25	13	1	1	233	16	164	43
PIGN	20	406	72	20	3	3	46	5	345	192
PIKR	12	510	32	10	0	1	399	15	135	342
GARN	7	161	17	6	0	0	136	28	60	16
LILY	10	213	27	10	1	0	174	60	67	55
MUDC	6	99	17	6	0	1	81	49	36	23
LTME	5	14	14	5	0	0	11	3	9	3
UNDW	13	1,366	40	13	1	0	434	232	947	229
OAKC	7	218	5	7	0	0	204	49	54	49
PIKC	4	15	0	4	0	0	14	5	1	3
HONY	6	135	7	6	0	0	132	32	9	98
ROOT	11	284	45	11	0	0	15	3	274	7
LINC	8	59	5	7	0	1	39	32	20	8

[1]For the JAMB (Jambo Creek) site, the fish Index of Biotic Integrity was computed according to Lyons and others (1996) for coldwater streams.

Table 18. Biological metrics computed from fish assemblages for 30 sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[Site list is sorted by urban intensity index (UII) values, from lowest to highest. Metrics in columns C–J were computed based on Lyons (1992)[1]; metrics in columns K–P were based on Barbour and others (1999); metrics in columns Q–U were computed based on Goldstein and Meador (2004). Site abbreviations are listed in table 1. Metric definitions are in appendix 1-10.]

Site abbreviation	K	L	M	N	O	P	Q	R	S	T	U
	OMNIfshE	INSCfshE	GENRfshE	INTMfshE	SENSfshE	TOLRfshE	COBBfish	MUDfish	ACCLfish	SIMPfish	COMPfish
JAMB	11.1	64.4	5.9	36.3	37.0	26.7	52.6	17.8	4.4	23.7	60.0
BLAK	2.9	21.9	33.3	62.3	.3	37.4	35.9	6.4	1.0	34.4	16.8
MEME	1.9	91.8	5.2	46.0	20.9	33.1	28.2	40.6	26.0	50.9	47.8
RIOC	18.6	65.5	15.4	52.7	.0	47.3	28.4	24.1	13.7	15.4	71.2
DEVL	7.6	64.4	26.1	37.1	20.7	42.2	53.4	18.5	8.5	41.0	35.9
KEWA	4.7	92.3	2.3	3.4	.0	96.6	6.8	89.8	90.2	3.3	91.4
BAIR	5.8	42.7	51.6	34.2	2.2	63.6	59.5	20.5	5.4	54.5	39.5
POIN	11.8	42.5	45.3	21.5	20.0	58.5	64.2	19.1	1.2	63.2	29.2
ASHW	16.9	69.7	11.2	4.5	.0	95.5	28.1	4.5	4.5	11.2	67.4
BLOT	4.1	38.9	.0	86.5	.0	13.5	4.1	11.9	18.1	.0	38.3
KILB	25.0	50.0	25.0	25.0	.0	75.0	37.5	37.5	37.5	25.0	37.5
HOOD	32.5	46.0	20.8	34.3	6.5	58.7	39.0	22.1	.3	20.8	46.0
SAWY	64.9	24.3	.0	21.6	.0	78.4	48.6	29.7	18.9	2.7	29.7
APPL	72.0	17.7	9.6	9.6	.0	90.4	74.5	10.9	.6	9.6	19.9
LANC	4.3	81.4	14.2	42.3	36.4	21.3	22.9	36.4	.4	14.2	45.1
BOWR	68.7	20.7	10.5	19.8	.0	80.2	37.8	51.1	.0	15.8	56.7
FOXR	3.9	92.2	.0	14.3	5.0	80.7	11.6	76.6	72.2	9.4	87.1
MENO	5.4	55.4	37.2	18.9	2.4	78.7	43.6	13.2	2.7	39.5	55.7
PIGN	1.2	85.0	3.9	58.4	30.3	11.3	12.8	14.8	1.0	25.4	47.8
PIKR	2.9	26.5	69.4	20.4	1.4	78.2	72.0	1.0	.0	70.6	9.0
GARN	17.4	23.6	45.3	15.5	.0	84.5	55.3	8.7	.0	45.3	30.4
LILY	28.2	31.5	34.7	18.3	.0	81.7	35.2	40.4	.5	34.7	64.8
MUDC	49.5	36.4	.0	18.2	.0	81.8	37.4	26.3	.0	.0	76.8
LTME	21.4	64.3	7.1	21.4	.0	78.6	28.6	14.3	7.1	7.1	64.3
UNDW	17.0	69.3	13.0	68.2	.0	31.8	29.6	67.3	.4	13.0	70.1
OAKC	22.5	24.8	52.3	6.4	.0	93.6	74.8	1.4	.5	52.3	25.2
PIKC	33.3	6.7	60.0	.0	6.7	93.3	86.7	13.3	.0	66.7	13.3
HONY	23.7	6.7	69.6	2.2	.0	97.8	83.7	11.9	.0	69.6	16.3
ROOT	1.1	96.5	2.1	94.7	.0	5.3	3.2	1.8	1.1	2.1	96.5
LINC	54.2	33.9	.0	33.9	.0	66.1	0.0	8.5	.0	13.6	32.2

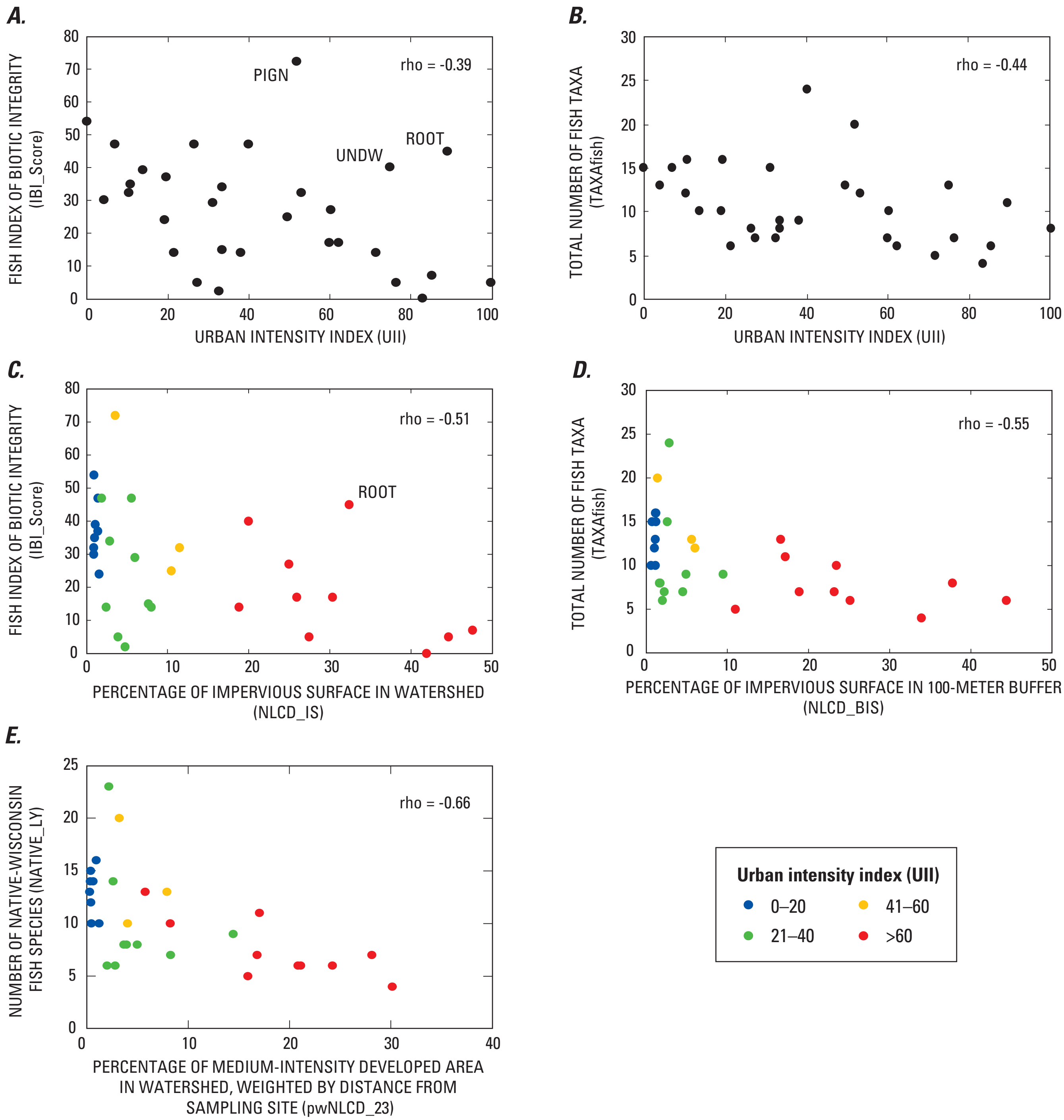


Figure 39. Relations between fish metrics and land-cover-derived urban metrics for 30 study sites in the Milwaukee to Green Bay, Wis., study area.

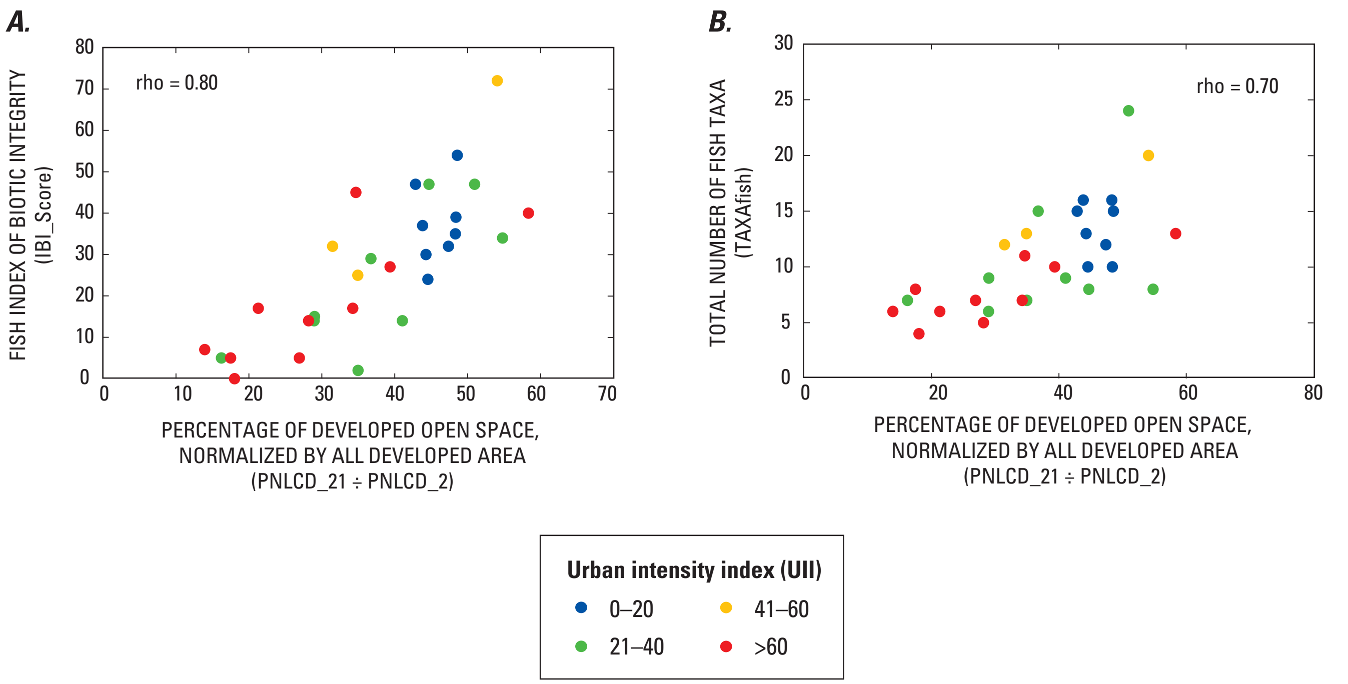


Figure 40. Relations between fish metrics and the percentage of developed open space (normalized by all developed area) for 30 study sites in the Milwaukee to Green Bay, Wis., study area.

The highest correlations between fish assemblages and water chemistry were during spring, especially for chloride (CHLOR), sulfate (SULFA), and pesticides. Higher concentrations of these chemicals correlated with negative changes in selected fish metrics, indicating degrading fish assemblages (fig. 41). Negative correlations between fish metrics and the number of pesticide detections, especially herbicides (acetochlor, ACETO) and total insecticide concentration (TICONC), were reflected in additional correlations between fish assemblages with PTI values for cladocerans (PTI_CLAD) and invertebrates (PTI_INV). Relations between fish metrics and PTI values for cladocerans and invertebrates may indicate an association with decreasing invertebrate abundance used by fish for food. Increases in these chemicals correlated with decreases in IBI scores and number of native fish (NATIVE_LY), increases in tolerant fish (TOLRfshE), and fish that prefer mud substrates (MUDfish). Increasing detections and concentrations of selected chemicals found in SPMDs correlated to decreases in several fish metrics indicative of good quality assemblages, especially the number of TAXAfish, abundance or number of fish (ABUNfish), NATIV_LY, percentage of accelerator-shape fish (ACCLfish), number of insectivores (INSC_LY), and number of rock-substrate spawning fish (LITHO_LY) (appendix 6).

Although temperature is well known as a critical characteristic that limits fish abundance and distribution, easy access to nearby larger streams (higher base flows) with moderate temperatures and the dominance of warmwater streams in this study may have reduced the significance of temperature measurements to fish at these urban sites. The numbers of fish taxa (TAXAfish) were only weakly related to daily stream temperature (fig. 42).

Several fish metrics correlated to hydrologic-condition metrics. Two indicators of good-quality fish assemblages, the fish IBI and Native_LY, decreased with increasing flashiness (day_pctchange) in the pre-ice period (fig. 43). Root River and Black Otter Creek, which has a nearby impoundment upstream, were outliers because of higher than expected fish IBI values. The metric day_pctchange was highly correlated with Richards-Baker flashiness (rb_flash), an index that has low inter-annual variability and thus may have substantial power in determining trends. A previously published application of this index was used to evaluate restoration to more natural flow regimes (Baker, 2004).

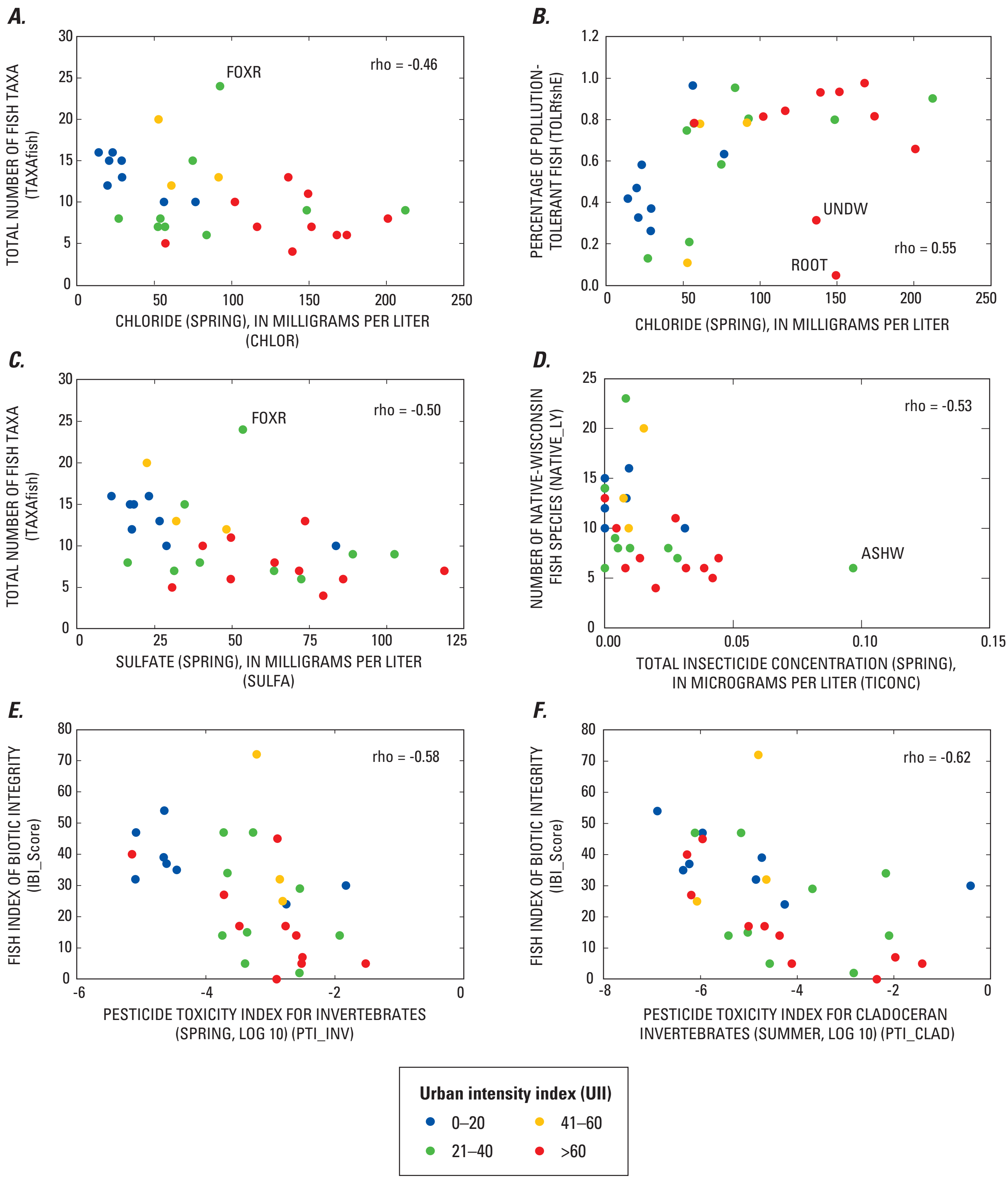


Figure 41. Relations of fish metrics and *A* through *D*, chemical concentrations, and *E* through *F*, the Pesticide Toxicity Index for 30 studies in the Milwaukee to Green Bay, Wis., study area.

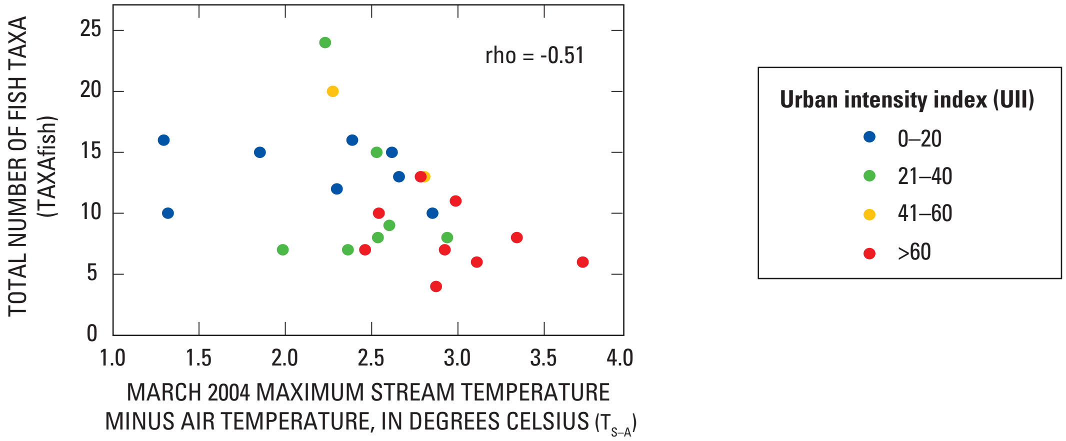
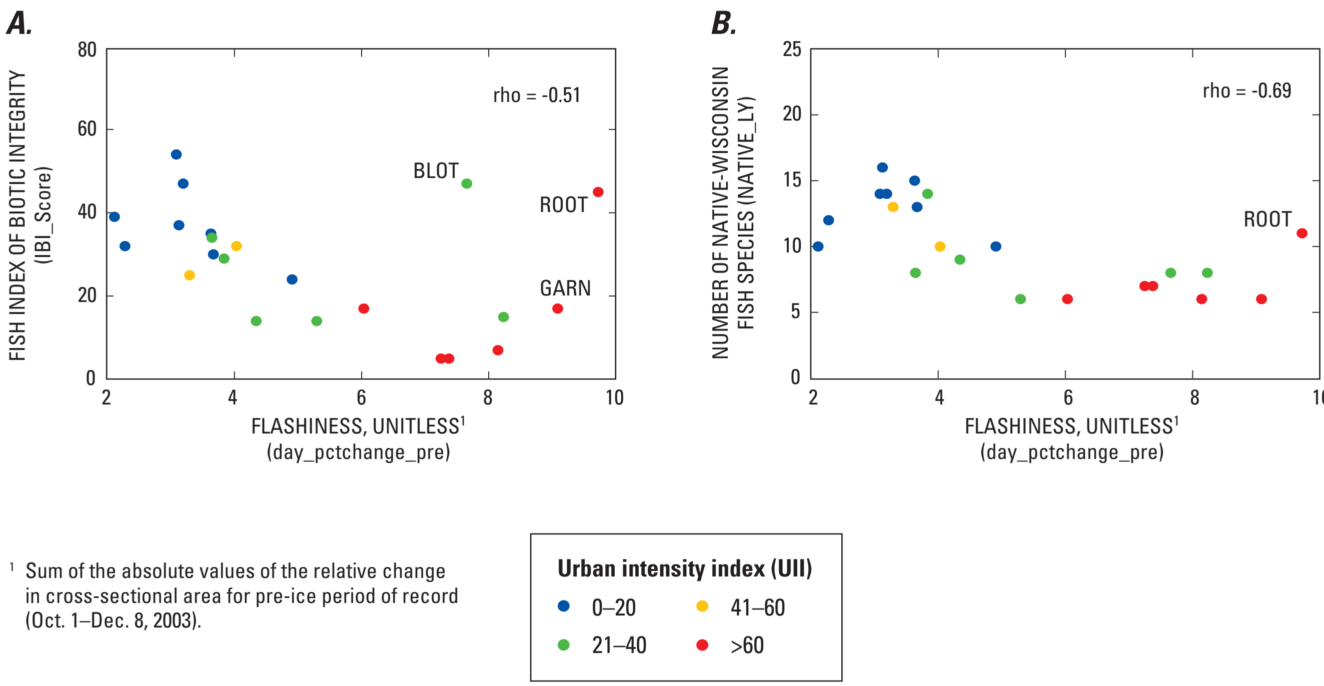


Figure 42. Scatterplots showing relation between monthly maximum stream temperature minus air temperature and total number of fish taxa for 26 study sites in the Milwaukee to Green Bay, Wis., study area.



[1] Sum of the absolute values of the relative change in cross-sectional area for pre-ice period of record (Oct. 1–Dec. 8, 2003).

Figure 43. Relations between fish metrics and hydrologic metrics for 22 study sites in the Milwaukee to Green Bay, Wis., study area.

In this study, a decrease in day_pctchange and rb_flash may be indicative of a more natural flow regime that would benefit healthier fish assemblages. Fish IBI, ABUNfish, LITHO_LY, and INSC_LY decreased with increases in the post-ice flashiness metric (periodr9) (fig. 44*A*, *B*; appendix 6) The fish IBI, TAXAfish, NATIVE_LY, and MUDfish increased with increasing small hydrograph changes (periodr1, post-ice); this supports the idea that small hydrologic disturbances may be beneficial (fig. 45*C–E*). Increasing bankfull discharge (Q_bnkfl) resulted in a low percentage of MUDfish but a high percentage of rock/cobble substrate fish (COBBfish); this may be a result of the removal of finer substrates with the increased discharge (fig. 45*A*, *B*). The percentage of accelerator-shape fish (ACCLfish), fish that are arrow-shaped (for example, pike), was positively correlated with the duration of high flow (MXH_95, pre-ice; MDH_90, post-ice); however, bankfull discharge (Q_bnkfl) was inversely related to ACCLfish, with increasing numbers of ACCLfish associated with bankfull flow less than 0.03 ($m^3/s/km^2$). The fish IBI and INSC_LY decreased with increasing maximum instantaneous peak flow normalized by drainage area (Qmax_instDA) and remained low when Qmax_instDA exceeded approximately 0.6 $m^3/s/km^2$ (fig. 45*D*). Although Qmax_instDA was not as successful in explaining fish variability as were hydrologic-condition metrics, this summary statistic is computed routinely at all USGS streamflow-gaging stations and is more readily available than are hydrologic-condition metrics.

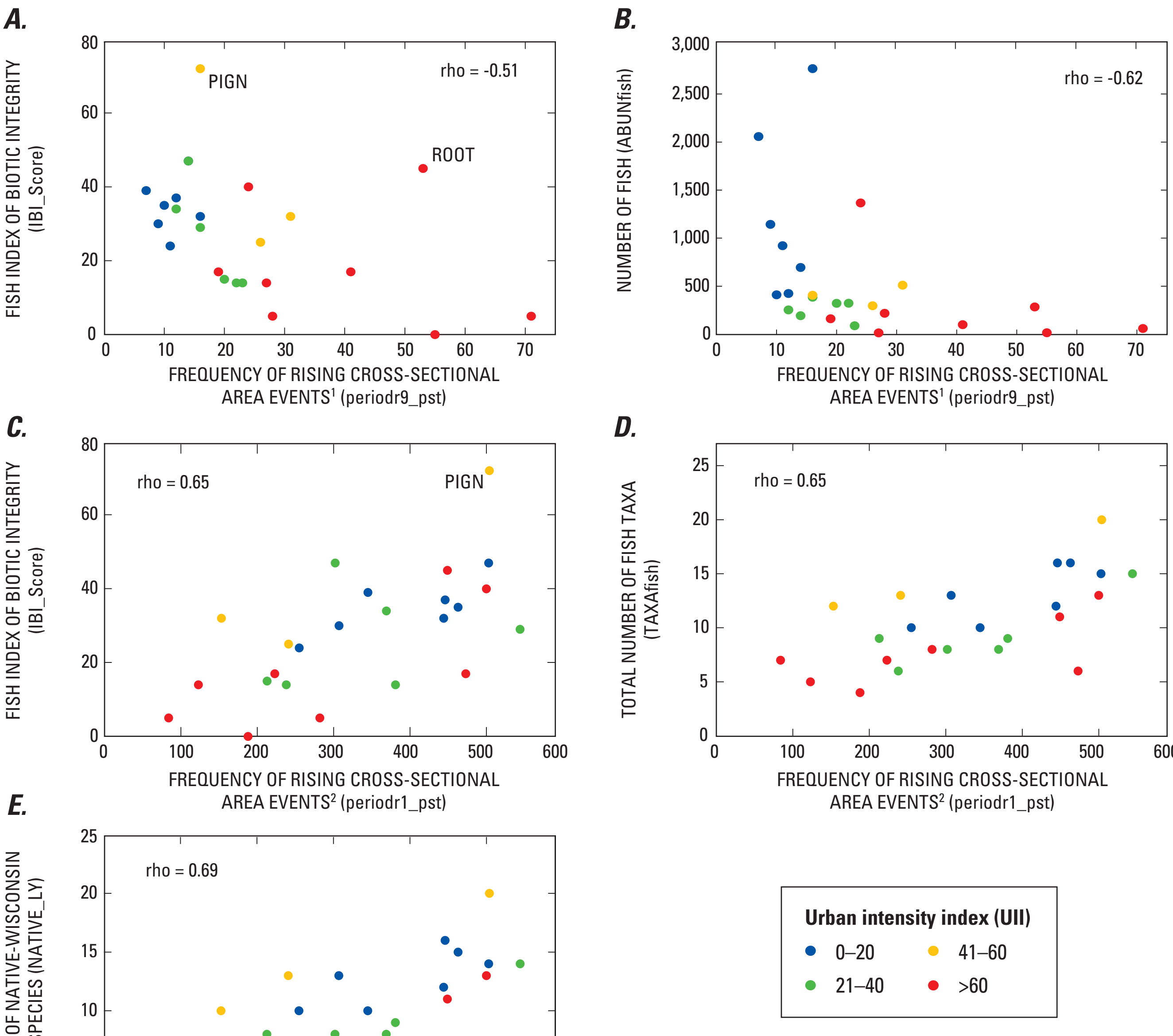
Results evaluating the relative influence of physical and chemical environmental characteristics on fish assemblages differed slightly between the direct method of CCA, using assemblage data, and the indirect method of correlations with DCA axes scores or fish metrics discussed above.

The most important environmental characteristics for fish assemblages, as indicated by relative lengths of arrows in the CCA ordination plot of all sites (fig. 46), were the number of herbicide detections (spring), percentage of pools in the reach, percentage of total impervious surface in the watershed (representative for chloride, medium to high-intensity developed urban land, and road indices), watershed slope, maximum instantaneous peak flow normalized by drainage area, dissolved oxygen (summer), percentage of streambank vegetative cover in the reach, and the Pesticide Toxicity Index (PTI) for cladocerans (summer). The primary negative characteristics were herbicide detections, PTI, total impervious surface, and peak flows; these represented chemical, physical-habitat, and hydrologic characteristics. Eigenvalues for CCA axes 1 through 4 were 0.350, 0.286, 0.246, and 0.169, respectively; Monte Carlo permutations tests showed that all axes were significant. CCA was able to distinguish among site groupings based more on the percentage of impervious surface and less on the UII (fig. 46). Sites with less than 10 percent impervious surface (UII $<$ 10) formed a separate group from sites with >25 percent impervious surface (UII $>$ 60) on the CCA ordination plot. Wang and others (2001) found that watershed impervious surface was the best indicator of degrading fish assemblages in southeastern Wisconsin because of urbanization. In the Upper Illinois River Basin urbanization study, fish IBI scores declined significantly (rho $<$ 0.77) with increasing percentages of urban land, total impervious surface, and road area in the watershed and stream riparian zone (Harris and others, 2005).

Summary of Biological Relations

Assemblages of metrics representing three groups of biota correlated to urban-associated metrics, but these groups did not always correlate similarly to the same environmental characteristics or stresses. Fish assemblages, represented by metrics such as the number of fish taxa (TAXAfish), were less strongly related to daily stream temperature than were invertebrate assemblages. Selected hydrologic-condition metrics explained variability in one or more groups of biota but not in other groups. For example, a low-flow metric in the pre-ice period (pct_5n) was strongly correlated to invertebrates but provided little insight for algae or fish (table 8). Hydrologic-condition metrics characterizing low flow (pct25n and pct_5n) for the pre-ice period correlated to several invertebrate metrics, although these same two hydrologic-condition metrics were not correlated with algal or fish metrics, or the UII. The maximum duration of low flow during the pre-ice period (MXL_10) was positively correlated with numerous algal metrics but not with invertebrates or fish.

During the post-ice period (March–October), invertebrate metrics correlated more strongly with hydrologic-condition metrics than did fish metrics in number of correlations and maximum rho values (table 8). The strongest correlation (rho $=$ 0.75) for this period was between the maximum duration of low flow (MXL_5) and mayfly taxa richness (EPEMR) (fig. 37*F*). Conversely, EPEMR was lower at flashier stream sites (higher day_pctchange) and decreased with increasing high flows (pct_99n) during the post-ice period. The pre-ice flashiness metric (day_pctchange) showed the most correlations to fish; the annual median-flow metric normalized by drainage area (Q_50DA) and the maximum duration of high flow (MXH_95) during the post-ice period showed the most correlations to invertebrates; the pre-ice low-flow duration metric (MXL_10) showed the most correlations to algae (table 8). The indicator of daily hydrograph change (day_pctchange) helped explain invertebrate and fish variability but did not help explain variation in algal assemblages among sites.



[1] When total rise of cross-sectional area is greater than or equal to 9 times the median total rise of the post-ice period of record (Mar. 16–Oct. 20, 2004).

[2] When total rise of cross-sectional area is greater than or equal to 1 times the median total rise of the post-ice period of record (Mar. 16–Oct. 20, 2004).

Figure 44. Relations between fish metrics and hydrologic metrics for 24 study sites in the Milwaukee to Green Bay, Wis., study area.

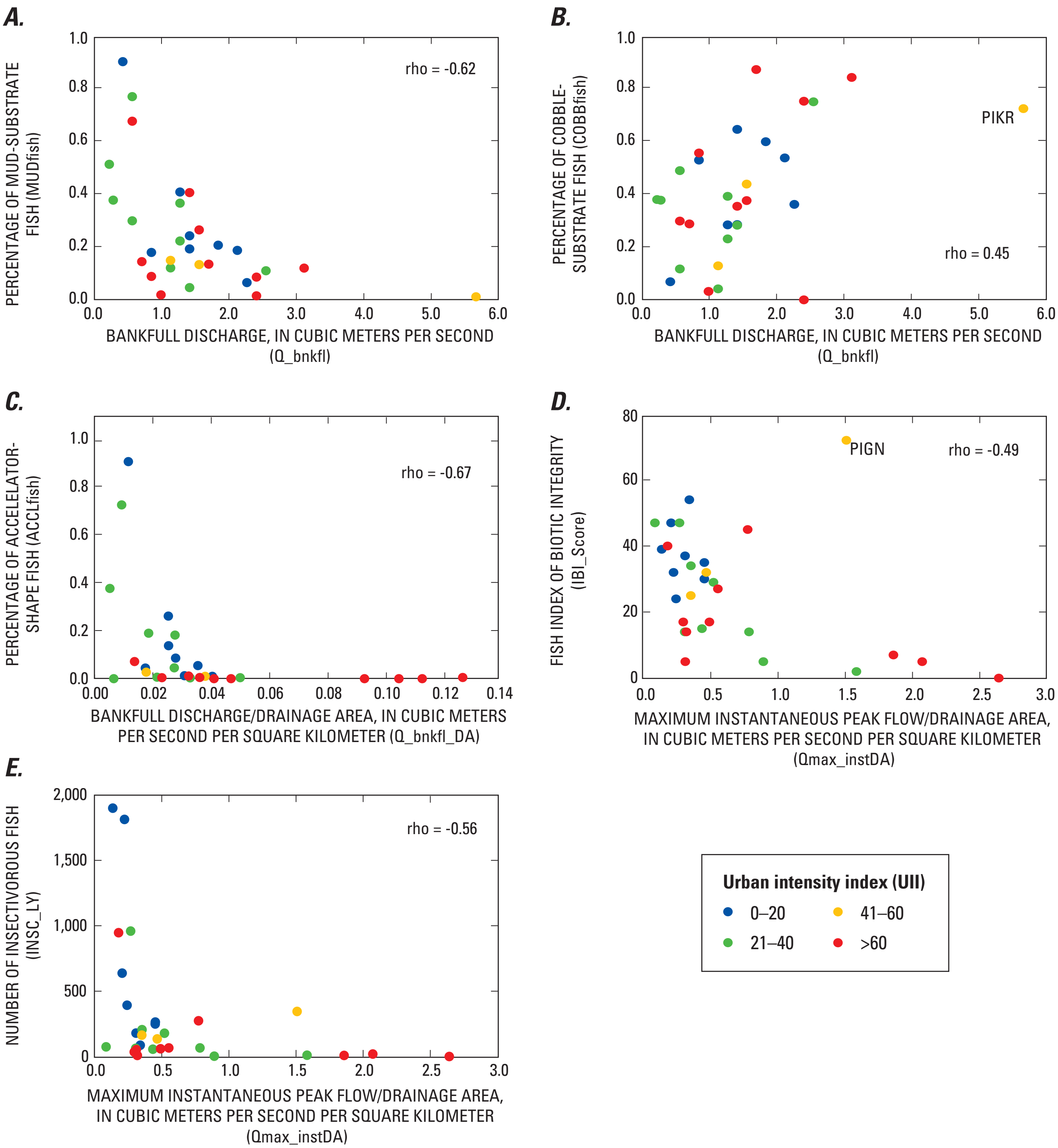


Figure 45. Relations between fish metrics and hydrologic metrics for 30 study sites in the Milwaukee to Green Bay, Wis., study area.

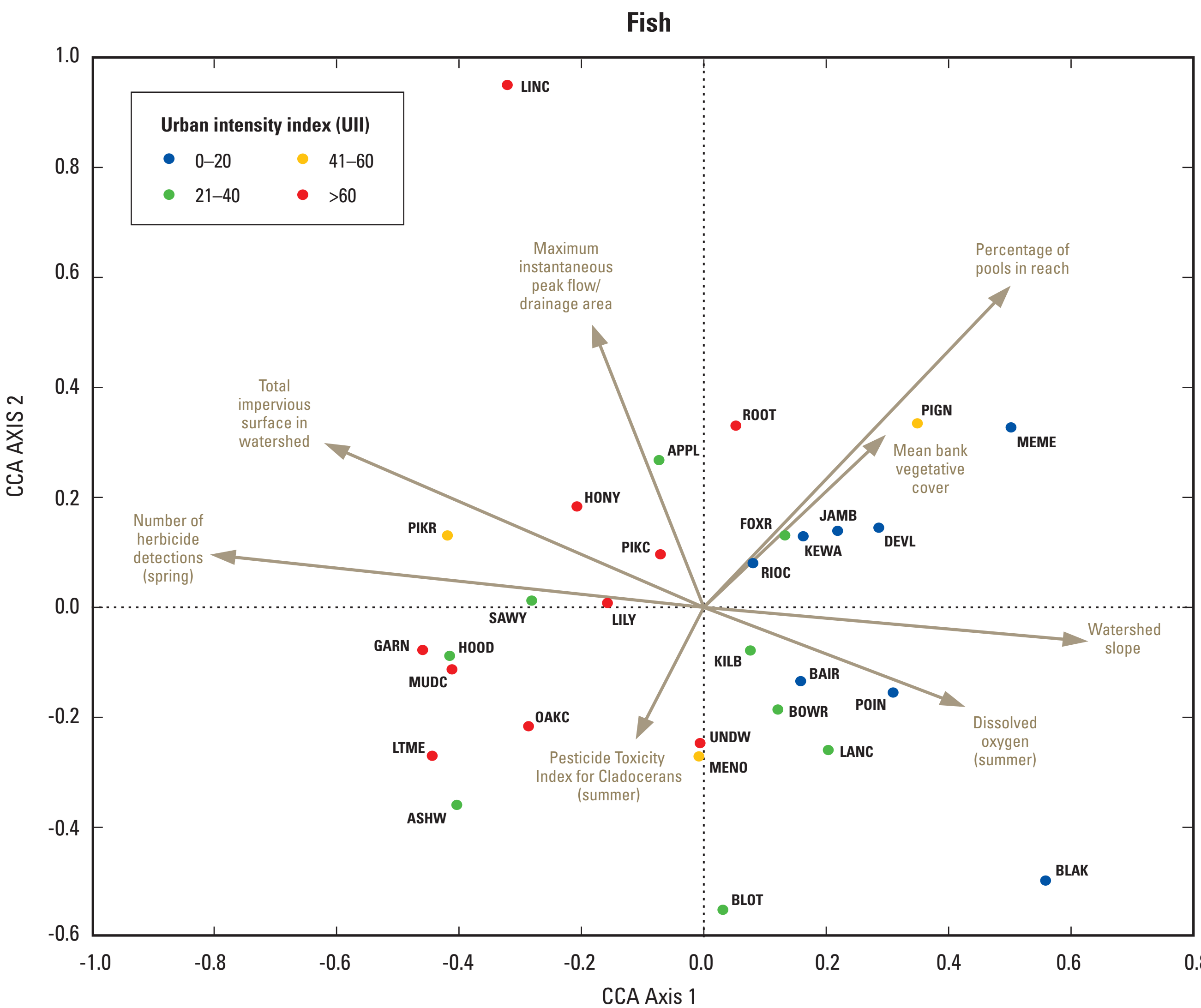


Figure 46. Relations of representative environments characteristics to fish assemblages for 30 study sites in the Milwaukee to Green Bay, Wis., study area.

Biotic metrics for algae, invertebrates, and fish correlated with selected measures of high flow and flashiness in study streams. The maximum duration of high flow during the post-ice period (MXH_95) correlated with many invertebrate metrics but did little to help understand algal or fish variability. Increased flashiness correlated with degraded algal, invertebrate, and fish populations (appendixes 4-6), suggesting that high infiltration soils in a watershed should be preserved. The pre-ice flashiness metric periodf3 correlated with numerous algal metrics, and the pre-ice high-flow metric (MXH_95) showed significant fish-metric relations. The median duration of high flows in the pre-ice period (MDH_95), a period of moderate but not extreme high flow, was positively related to many invertebrate metrics. As development increased in the 100-m riparian zone (NLCD_S22, NLCD_S23), the median duration of high flows (MDH_95) decreased during the pre-ice period (table 9). Medium-intensity developed urban land in the riparian zone showed the strongest negative relation to streamflow (fig. 21*E*). This relation was greater than the relation between MDH_95 and the overall percentage of urban land in the watershed (rho = -0.62), an indication that less development in the riparian zone may be beneficial to invertebrate assemblages.

Metrics representing assemblages for each group of biota correlated to increases in total impervious surface in the watershed, along with increases in medium and high-intensity developed urban land, chloride concentration, and road indices. Invertebrate and fish assemblages were negatively affected by increasing total impervious surface (fig. 47*A*, *B*), and values greater than approximately 10 percent impervious surface corresponded to points at which these assemblages were less likely to be good quality. The relation between fish IBI and impervious surface in the watershed or 100-m riparian zone is similar to the wedge-shaped graph discussed by Cade and Noon (2003) where the independent variable defines the upper limit; however, other limiting factors are not addressed in this relation. Roy (2006) found stream biotic assemblages can degrade at low levels of urbanization, specifically at 10 to 15 percent impervious surface. Harris and others (2005) found that most high values for invertebrate EPT metrics and fish IBIs were from sites with less than 10 percent developed land, and values were low for these metrics beyond 20 to 25 percent developed urban land.

Many possible vectors could translate the effect of impervious surface to stream biota; hydrology is one such vector. Increased stream flashiness (periodr9) during the post-ice period correlated to decreased invertebrate taxa richness in RTH and QMH taxa combined (RICH_qq) with a slope breakpoint at 20 events (fig. 48*A1*). Four out of 24 sites with the highest taxa richness showed less than approximately 20 flashy events during the post-ice period. The amount of impervious surface in the watershed (along with impervious type, location, and connectivity) was an important factor in determining flashiness. In this study, 20 flashy events (~2.5 events per month) corresponded to approximately 5 to 10 percent impervious surface (fig. 48*A2*). A value of 5 to 10 percent impervious surface, using stream flashiness (periodr9) during the post-ice period as the intermediate vector, corresponded to the same break point in invertebrate taxa richness (RICH_qq) as the direct watershed imperviousness/taxa richness scatterplot (fig. 48*C*).

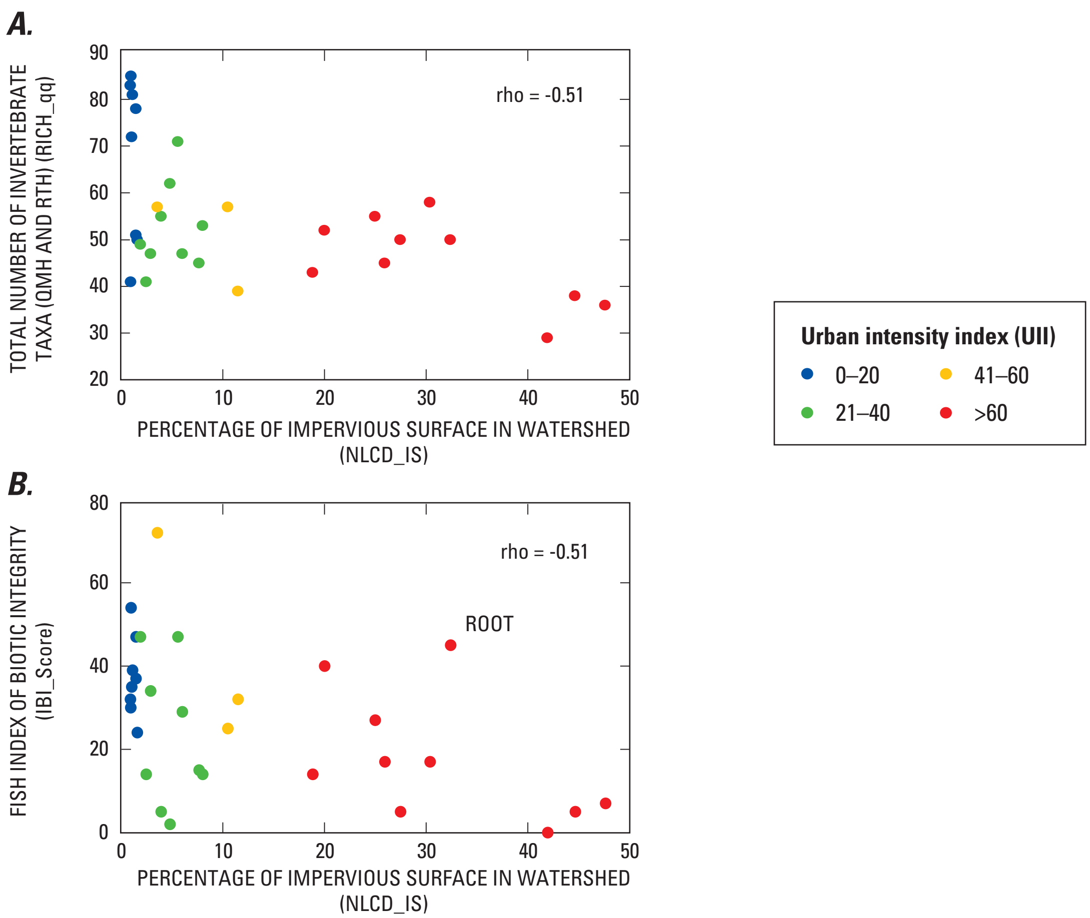
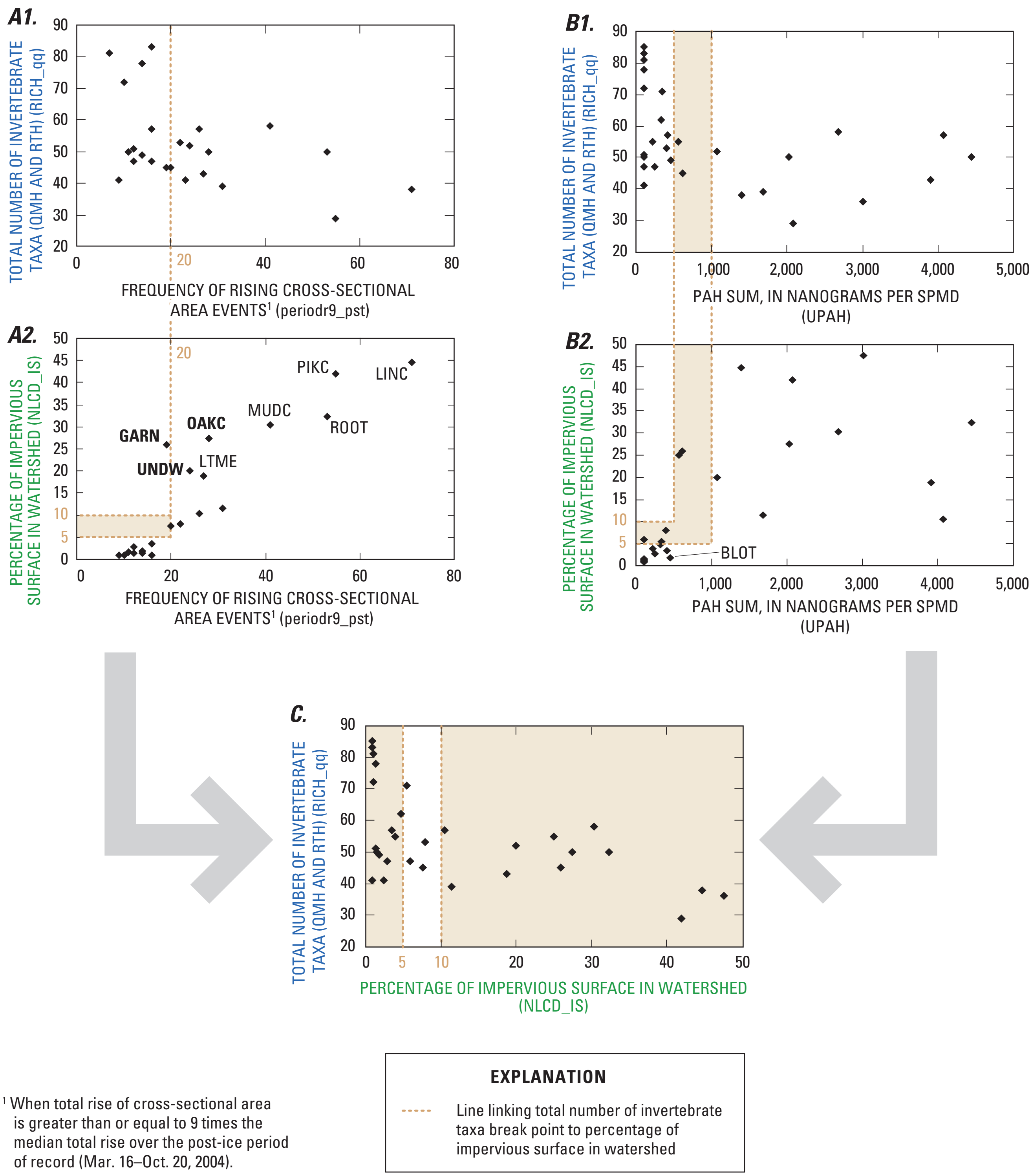


Figure 47. Relation between invertebrate taxa richness (RTH and QMH samples) and fish Index of Biotic Integrity to impervious surface in the basin at 30 sites in the Milwaukee to Green Bay, Wis., study area.



[1] When total rise of cross-sectional area is greater than or equal to 9 times the median total rise over the post-ice period of record (Mar. 16–Oct. 20, 2004).

Figure 48. Relation between total number of invertebrate taxa (in RTH and QMH samples) and percentage of impervious surface in watershed, using transitional vectors (flashiness and polycyclic aromatic hydrocarbons [PAHs]) for the Milwaukee to Green Bay, Wis., study area.

Chemistry is another possible means to translate the effects of impervious surface to stream biota. Runoff from impervious surfaces such as roadways, rooftops, and parking lots often drains into receiving waters that include streams. Impervious surfaces have been found to contain high concentrations of PAHs (Van Metre and others, 2000). This study found a relation between the sum of four PAHs (pyrene, phenanthrene, fluoranthene, and benzo(a)pyrene in nanograms per SPMD and invertebrate taxa richness (RICH_qq), fig. 48*B1*) with a slope breakpoint at ~750 nanograms PAH per SPMD. After about 500 to 1,000 nanograms per SPMD, high values of invertebrate taxa richness were no longer found. In addition, an increasing number of high PAH concentrations were found above 10 percent total impervious surface (fig. 48*B2*); this roughly corresponded to the imperviousness (5 to 10 percent) where significant decreases in taxa richness were observed (fig. 48*C*).

Although agricultural land cover has been found to negatively influence the health of aquatic ecosystems in streams in other studies, the effects of urbanization in this study were found to outweigh the agricultural effects (in agricultural areas, there tends to be more variability in aquatic ecosystem health). Nonetheless, legacy land-use effects on ecosystems can last decades or longer and therefore effects from agriculture are likely to be embedded in any responses to urbanization by streams and biota in our study (Foster and others, 2003).

Six annual streamflow statistics (Q_max, Q_10, Q_50, Q_90, Qmax_instDA, and Q50_DA) that are computed routinely for USGS streamflow-gaging stations were useful in explaining some variability in invertebrate or fish assemblages among sites (table 8). Two high-flow variables, bankfull flow (Q_bnkflDA) and Qmax_instDA, were negatively correlated with fish and invertebrate populations; Spearman rho correlations ranged from -0.54 to -0.67. As with fish assemblages, Qmax_instDA was negatively correlated with invertebrate metrics indicative of healthy invertebrate assemblages. The annual median-flow statistic normalized by watershed area (Q_50DA) was useful in explaining numerous invertebrate metrics but did little to explain algal or fish variability. This emphasizes the importance of using multiple indicators of hydrologic change to understand effects on biota in urban and urbanizing streams.

Summary and Conclusions

A natural landscape of forests, wetlands, and grasslands is porous and allows precipitation to filter slowly into the ground. In contrast, the urban landscape has many non-porous or impervious surfaces in the form of rooftops, paved roads, and parking lots that replace once-porous surfaces. These impervious surfaces prevent precipitation from infiltrating and increase the speed and volume of surface runoff. Urbanization often has more severe hydrologic effects than do agriculture or logging. In addition to increased surface runoff, urbanization presents additional impacts that include increased pollutant loads (including sediment and chemicals), increased water temperatures, and habitat destruction. These physical and chemical changes to urbanizing streams often have negative effects on biological communities.

Beginning in 2002, the National Water-Quality Assessment program (NAWQA) of the U.S. Geological Survey (USGS) conducted studies to determine the effects of urbanization on stream ecosystems in selected metropolitan areas across the U.S. During 2003 and 2004, 30 stream sites in or near the cities of Milwaukee and Green Bay were selected to investigate effects of urbanization on physical habitat, hydrology, water chemistry, and aquatic biology along an agriculture-to-urban land-use gradient. GIS data were used to characterize natural landscape features that defined the environmental setting and the degree of urbanization within each stream watershed. The sites were selected based on design components that included minimizing the natural variation in the physical setting and local site conditions across study watersheds and maximizing the range of urbanization. An urban intensity index (UII) was assigned to each stream site to identify a gradient of urbanization within relatively homogeneous environmental settings. Variables used in the UII represented the major categories of urbanization and included road infrastructure, riparian land, watershed land cover, and socioeconomic variables that characterized the urban setting and population. The study used a substitution of space for time, which assumes that temporal trends at a site (in this case, increases in urban land and population) will be similar to spatial trends found among sites with varying amounts of urban land.

Continuous monitoring of stream stage and water temperature at the sites was conducted from October 2003 to October 2004. Each site was sampled for measurements of physical habitat, water-quality parameters (nutrients, chloride, sulfate, dissolved and particulate inorganic and organic carbon, pesticides, and suspended sediment), and aquatic biota (algal, macroinvertebrate, and fish assemblages). In addition, semipermeable membrane devices (SPMDs) were deployed to assess potential toxicity at each location.

Of the habitat characteristics, only those reflective of channel enlargement (bankfull-channel area and length of bank erosion) increased with increasing urbanization. Other features such as geomorphic-channel units and substrate were related to topography and local slope.

Results from this study indicate that more riffles were present in reaches with subtle increases in slope, while reaches with a relatively large number of pools showed frequent rises associated with small events. Reaches with large substrate sizes, low percentages of silt cover, and low percentages of embeddedness showed a combination of relatively steep slopes and high unit-area bankfull discharges.

Watershed inputs of runoff and potential sediment delivery are accounted for, but local boundary conditions and history of channel modifications, as well as upstream/downstream geologic controls and human channel alterations may explain as much, if not more, of the habitat variability. Based upon an hourly streamflow record at a stream site, 54 hydrologic condition metrics were calculated to summarize hydrologic variability; the rate of change of areas (flows); and the magnitude, frequency, and duration of high- and low-flow (area) periods. These metrics may explain runoff changes associated with urbanization, but they cannot be used alone to predict habitat or geomorphic response. In addition, the age and type of bank stabilization and grade control influence not only habitat conditions, but also the scientists' ability to recognize and record human-made features such as distinguishing between riprap and glacial boulders. Stream-stabilization history (at the reach, upstream, and downstream) needs to be identified to assist in the interpretation of habitat characteristics and geomorphic responses to urbanization.

Hydrologic changes were characterized using basic streamflow characteristics as well as hydrologic-condition metrics. A number of hydrologic-condition metrics, including stream flashiness and duration of high flow, post-ice period (March 16–October 30) showed a strong relation to the UII. Stream flashiness (daily), pre-ice period (October 1 to December 8) showed a strong positive relation with urban land-use. The maximum duration of high flow was inversely correlated with urban land-use during the pre-ice period. These findings indicate urbanization often promotes frequent, steep hydrograph rises and shorter high-flow durations.

Water samples were collected twice at all sites—once in late spring (mid-May to early June 2004) and again during ecological sampling in summer (August–September 2004). The summer chemistry data were considered reflective of water-quality conditions that would have immediate impact on biological communities at the sites.

Spring concentrations of chloride, prometon, and diazinon showed positive correlations with the urban intensity index. Chloride and prometon showed a number of positive correlations to increases in developed urban land, size, location and distance of urban patches, and impervious surface. Diazinon and sulfate, to a lesser extent, showed positive correlations to a smaller number of the same urban-landscape variables.

Summer concentrations of chloride were the only analyte to show a significant correlation to the UII. Summer chloride concentrations had the most significant, positive correlations to urban-related variables. The strongest relations for the herbicides (atrazine, metolachlor, and 2-Chloro-4-isopropylamino-6-amino-s-triazine) were to increasing cultivated land in the watershed.

The SPMD toxicity tests and polycyclic aromatic hydrocarbon (PAH) concentrations were similar to the chloride results, with the strongest relations to the urban variables for percentage of impervious surface, road infrastructure, urban land-cover, size, location, and density of urban-land cover patches. Chloride concentration and SPMD data indicate a significant change in results when the percentage of impervious surface in the watershed is greater than 8 percent. The lower chloride and PAH concentrations and SPMD toxicity results between 19 and 26 percent impervious surface could be a result of the lower road-area and traffic indices at these sites. These strong, positive correlations with urbanization would indicate that automobiles and the infrastructure to support automobiles are a significant source of chloride and PAHs in this study area.

Oxygen tolerance, pollution sensitivity, and other metrics of high-quality algal assemblages were reduced when non-urban environmental characteristics such as percentage of wetlands in the 100-m riparian zone and reduced stream flashiness were also reduced. These results also suggest negative effects on algal assemblages with increases in percentages of developed urban land, population density, and road-area density.

Several urban-associated environmental characteristics were among the most important for explaining variations in invertebrate assemblages among sites: stream discharge in the spring and the discharge exceeded 50 percent of the time as normalized by drainage area, total impervious surface (also representative of chloride, medium- and high-intensity developed urban land, and road indices), and stream flashiness. Several characteristics that may or may not be associated with urbanization were also of importance to invertebrate assemblages: summer total concentration of pesticides, summer nitrite concentration, average bankfull-channel width-to-depth ratio, herbaceous upland natural/semi-natural vegetation in the 100-m riparian zone, percentage of riffles in the reach, Froude number, spring water temperature, and streambed-substrate stability.

Decreases in fish IBI scores, total number of fish taxa, and number of native fish taxa were associated with increasing values of the UII and urban-associated characteristics. Multivariate analyses of fish assemblages indicated that, like invertebrates and algae, fish assemblages could be related to several urban-associated environmental characteristics (including total impervious surface) and several environmental characteristics that are not necessarily the result of urbanization: spring herbicide detections, percentage of pools in the reach, watershed slope, summer maximum instantaneous peak flow normalized by drainage area, summer dissolved oxygen, bank vegetative cover, and summer pesticide toxicity index (PTI) values for cladocerans). Variations in fish assemblages correlated more with chemical characteristics measured in spring than summer, especially for chloride, sulfate, alkalinity/bicarbonate, and pesticides.

The health and quality of biological communities can be affected by environmental characteristics in the watershed and riparian zone. Total impervious surface in the watershed was highly correlated to that in the riparian zone in our study; this close association made it difficult to separate effects of impervious surface in the watershed compared to the riparian zone. Previous studies have found that stream biotic assemblages can degrade at low levels of urbanization, specifically at 10 to 15 percent total impervious surface in the watershed. Study results also suggest that healthier invertebrate and fish assemblages were less likely when watershed impervious surface exceeded 10 percent, and this value of impervious surface corresponded to a UII of approximately 50 in this study.

Urbanization in the Milwaukee to Green Bay, Wis., study area is replacing agricultural land that has been the dominant land use for many years. In this study, as land cover changed from agriculture to urban, adverse changes in streams were found with respect to hydrology, stream chemistry, and aquatic biota. Differences in algal, invertebrate, and fish assemblages among study streams showed relations to chemical, physical, and hydrologic indicators of urbanization. Increased stream flashiness, decreased base flows, and increased contaminant runoff contribute to the loss of aquatic habitat and degraded water quality. Results from this study emphasize the importance of assessing multiple indicators of urbanization—geomorphology, land use/land cover, hydrology, and chemistry—to understand potential effects on aquatic biota in urbanizing streams.

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Appendix 1–1. Sources of geographic information system (GIS) and digital information used to derive characteristics for the Milwaukee to Green Bay, Wis., study area.

[km, kilometer; m, meter; USGS, U.S. Geological Survey; USEPA, U.S. Environmental Protection Agency; TIGER, Topologically Integrated Geographic Encoding and Referencing; WPDES, Wisconsin Pollutant Discharge Elimination System; WDNR, Wisconsin Department of Natural Resources; NLCD, National Land Cover Database; USDA, U.S. Department of Agriculture; STATSGO, State Soil Geographic Database]

Characteristic type	Note	Scale	Reference
Watershed boundaries	Developed from digital-elevation models	1:24,000	U.S. Geological Survey, 2005a
Streams	USGS national hydrography data	1:100,000	U.S. Geological Survey, 2005b
Population and housing	U.S. Census Bureau data as packaged by GeoLytics, Inc.	1:100,000	GeoLytics, 2001
Climate	Daymet 1-km resolution data	1:1,000,000	Daymet, 2005
Ecological regions	USEPA Ecoregion boundaries	1:7,500,000 (Level III)	Omernik, 1987
Hydrologic landscape regions	USGS hydrologic landscape regions	1:1,000,000	Wollock, 2003
Infrastructure	Roads (Census TIGER roads)	1:100,000	GeoLytics, 2001
	WPDES surface water outfalls	1:24,000	Wisconsin Department of Natural Resources, 2002, personal commun., unpublished database
	Toxic-release inventory locations	1:100,000	U.S. Environmental Protection Agency, 2005b
	WDNR Dam Safety database	1:24,000	Wisconsin Department of Natural Resources, 2002, personal commun., unpublished database
Land cover and imperviousness (30-m)	NLCD compatible	1:100,000	U.S. Geological Survey, 2006a; Falcone and Pearson, 2006
Landscape pattern metrics (30-m)	Anderson Level I land-cover metrics derived from FRAGSTATS	1:100,000	McGarigal and Marks, 1995
Soils	Based on Shirazi version of USDA STATSGO data	1:250,000	U.S. Department of Agriculture, 1994; Shirazi and others, 2001a, 2001b, 2001c
Texture of surficial deposits	Based on *Quaternary Geologic Atlas of the United States*	1:1,000,000	Richmond and Fullerton, 1983 and 1984
Topography	Derived from digital-elevation models	1:24,000–100,000	U.S. Geological Survey, 2005a

Appendix 1–2. Geographic information system (GIS) derived characteristics for 30 sites in the Milwaukee to Green Bay, Wis., study area.

[km^2, square kilometer; km, kilometer; cm, centimeter; m, meter; m/km, meter per kilometer; °C, degrees Celsius; ha, hectacres; g/m^2, gram per square meter; cm/cm, centimeter per centimeter; mm, millimeter; %, percent; <, less than; >, greater than; CFCC, census feature class code; TIGER, Topologically Integrated Geographic Encoding and Referencing; USEPA, U.S. Environmental Protection Agency; WPDES, Wisconsin Pollutant Discharge Elimination System; WDNR; Wisconsin Department of Natural Resources; NLCD, National Land Cover Database; MRLC, Multi-Resolution Land Characteristics Consortium; USDA, U.S. Department of Agriculture]

Characteristic abbreviation	Definition
	Drainage characteristics (scale 1:24,000–1:100,000)
SQKM	Watershed area (km^2)
STREAMKM	Length of 1:100,000-scale stream centerline within watershed (km)
STREAMDN	Stream density (stream kilometers divided by watershed area)
	Population and housing characteristics (scale 1:100,000)
POP2000	2000 population (2000 census block based)
POP1990	1990 population (2000 census block based)
POP90_00	Proportional change in population from 1990–2000 (2000 census block based)
POPDEN00	2000 population density (people per square mile) (2000 census block based)
POPDEN90	1990 population density (people per square mile) (2000 census block based)
SEI_1	Socioeconomic Index 1: principal component 1 for 63 socioeconomic variables (block-group based)
SEI_2	Socioeconomic Index 2: principal component 2 for 63 socioeconomic variables (block-group based)
SEI_3	Socioeconomic Index 3: principal component 3 for 63 socioeconomic variables (block-group based)
SEI_4	Socioeconomic Index 4: principal component 4 for 63 socioeconomic variables (block-group based)
POPDENKM	2000 population density (persons per square kilometer) (block-group based)
HHDEN	Household density (occupied housing units per square kilometer) (block-group based)
HUDEN	Density of housing units (housing units/square kilometer) (block-group based)
POCC_G65	Percentage of population 65 or older (block-group based)
PPURBAN	Percentage of population living in urban area (block-group based)
PPRURAL	Percentage of population living in rural area (block-group based)
PPWHITE	Percentage of population race who are white (block-group based)
PPBLACK	Percentage of population race who are black (block-group based)
PPNAM	Percentage of population race who are Native American (block-group based)
PPASIA	Percentage of population race who are Asian (block-group based)
PPMALE	Percentage of population who are male (block-group based)
PPFEMALE	Percentage of population who are female (block-group based)
PHFAM	Percentage of households occupied by a family (block-group based)
PHNONFAM	Percentage of households occupied by a nonfamily (block-group based)
PHO_L3P	Percentage of households ocuupied by less than three people (block-group based)
PHO_G4P	Percentage of households occupied by four or more people (block-group based)
PC_US	Percentage of citizens born in U.S. (block-group based)
PC_INSTAT	Percentage of citizens born in State of residence (block-group based)

Appendix 1–2. Geographic information system (GIS) derived characteristics for 30 sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[km^2, square kilometer; km, kilometer; cm, centimeter; m, meter; m/km, meter per kilometer; °C, degrees Celsius; ha, hectacres; g/m^2, gram per square meter; cm/cm, centimeter per centimeter; mm, millimeter; %, percent; <, less than; >, greater than; CFCC, census feature class code; TIGER, Topologically Integrated Geographic Encoding and Referencing; USEPA, U.S. Environmental Protection Agency; WPDES, Wisconsin Pollutant Discharge Elimination System; WDNR; Wisconsin Department of Natural Resources; NLCD, National Land Cover Database; MRLC, Multi-Resolution Land Characteristics Consortium; USDA, U.S. Department of Agriculture]

Characteristic abbreviation	Definition
PC_OUTST	Percentage of citizens born in other States in the U.S. (block-group based)
PC_NONUS	Percentage of population who were born outside the U.S. (block-group based)
PP_L5Y	Percentage of population less than 5 years old (block-group based)
PP_SH95	Percentage of population living in same house as in 1995 (block-group based)
PC_CTY95	Percentage of citizens living in same county more more than 5 years (since 1995) (block-group based)
PC_ST95	Percentage of citizens living in same State more more than 5 years (since 1995) (block-group based)
PM_GT25Y	Percentage of male population greater than 25 years of age (block-group based)
PF_GT25Y	Percentage of female population greater than 16 years of age (block-group based)
PHS_G25	Percentage of population greater than 25 years old who have high school degrees (block- group based)
PBCH_G25	Percentage of population greater than 25 years old who have bachelor's degrees (block-group based)
PF_GT16E	Percentage of female population greater than 16 years of age who are employed (block-group based)
PM_GT16E	Percentage of male population greater than 16 years of age who are employed (block-group based)
PHHI_L10	Percentage of households with income less than 10,000 (dollars) (block-group based)
PHHI_L20	Percentage of households with income less than 20,000 (dollars) (block-group based)
PHHI_L30	Percentage of households with income less than 30,000 (dollars) (block-group based)
PPOP_POV	Percentage of population with income below the poverty level (block-group based)
PFAM_POV	Percentage of families with income below the poverty level (block-group based)
PHH_POV	Percentage of households having an income below poverty level (block-group based)
P_OCCUPY	Percentage of housing units that are occupied (block-group based)
P_VACANT	Percentage of housing units that are vacant (block-group based)
P_OWN	Percentage of total housing units that are owner occupied (block-group based)
P_RENT	Percentage of total housing units that are occupied by renters (block-group based)
PH_1PERS	Percentage of households occupied by one person (block-group based)
PH_2PERS	Percentage of households occupied by two persons (block-group based)
PH_3PERS	Percentage of households occupied by three persons (block-group based)
PH_4PERS	Percentage of households occupied by four persons (block-group based)
PH_5PERS	Percentage of households occupied by five persons (block-group based)
PH_6PERS	Percentage of households occupied by six persons (block-group based)
PH_7PERS	Percentage of households occupied by seven or more persons (block-group based)
PHU_L5	Percentage of housing units built between 1995–2000 (block-group based)
PHU_L10	Percentage of housing units built between 1990–2000 (block-group based)
PHU_L20	Percentage of housing units built between 1980–2000 (block-group based)

Appendix 1–2. Geographic information system (GIS) derived characteristics for 30 sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[km^2, square kilometer; km, kilometer; cm, centimeter; m, meter; m/km, meter per kilometer; °C, degrees Celsius; ha, hectacres; g/m^2, gram per square meter; cm/cm, centimeter per centimeter; mm, millimeter; %, percent; <, less than; >, greater than; CFCC, census feature class code; TIGER, Topologically Integrated Geographic Encoding and Referencing; USEPA, U.S. Environmental Protection Agency; WPDES, Wisconsin Pollutant Discharge Elimination System; WDNR; Wisconsin Department of Natural Resources; NLCD, National Land Cover Database; MRLC, Multi-Resolution Land Characteristics Consortium; USDA, U.S. Department of Agriculture]

Characteristic abbreviation	Definition
PHU_G20	Percentage of housing units built prior to 1979 (1939 or earlier to 1979) (block-group based)
PHU_G30	Percentage of housing units built prior to 1969 (1939 or earlier to 1969) (block-group based)
PHU_G40	Percentage of housing units built prior to 1959 (1939 or earlier to 1959) (block-group based)
PHU_G50	Percentage of housing units built prior to 1949 (1939 or earlier to 1949) (block-group based)
PHU_G60	Percentage of housing units built prior to 1939 (block-group based)
PHUT	Percentage of occupied housing units using utility gas (natural gas) as fuel (block-group based)
PHLP	Percentage of occupied housing units using liquid petroleum gas as fuel (block-group based)
PHEL	Percentage of occupied housing units using electricity as fuel (block-group based)
PHOIL	Percentage of occupied housing units using oil as fuel (block-group based)
PHWOOD	Percentage of occupied housing units using wood as fuel (block-group based)
PERCAPIN	Per capita income (block-group based)
MEDHHI	Median household income, 2000 (dollars) (block-group based)
MFAMINC	Median family household income (block-group based)
MNFAMINC	Median nonfamily household income (block-group based)
Climate characteristics (scale 1:1,000,000)	
MAAT	Mean annual air temperature (based on period 1980–1997) (°C)
MT_JAN	Mean January monthly air temperature (°C)
MT_FEB	Mean February monthly air temperature (°C)
MT_MAR	Mean March monthly air temperature (°C)
MT_APR	Mean April monthly air temperature (°C)
MT_MAY	Mean May monthly air temperature (°C)
MT_JUN	Mean June monthly air temperature (°C)
MT_JUL	Mean July monthly air temperature (°C)
MT_AUG	Mean August monthly air temperature (°C)
MT_SEP	Mean September monthly air temperature (°C)
MT_OCT	Mean October monthly air temperature (°C)
MT_NOV	Mean November monthly air temperature (°C)
MT_DEC	Mean December monthly air temperature (°C)
MAP	Mean annual precipitation (based on period 1980–1997) (cm)
MP_JAN	Mean January monthly precipitation (cm)
MP_FEB	Mean February monthly precipitation (cm)
MP_MAR	Mean March monthly precipitation (cm)

Appendix 1–2. Geographic information system (GIS) derived characteristics for 30 sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[km^2, square kilometer; km, kilometer; cm, centimeter; m, meter; m/km, meter per kilometer; °C, degrees Celsius; ha, hectacres; g/m^2, gram per square meter; cm/cm, centimeter per centimeter; mm, millimeter; %, percent; <, less than; >, greater than; CFCC, census feature class code; TIGER, Topologically Integrated Geographic Encoding and Referencing; USEPA, U.S. Environmental Protection Agency; WPDES, Wisconsin Pollutant Discharge Elimination System; WDNR; Wisconsin Department of Natural Resources; NLCD, National Land Cover Database; MRLC, Multi-Resolution Land Characteristics Consortium; USDA, U.S. Department of Agriculture]

Characteristic abbreviation	Definition
MP_APR	Mean April monthly precipitation (cm)
MP_MAY	Mean May monthly precipitation (cm)
MP_JUN	Mean June monthly precipitation (cm)
MP_JUL	Mean July monthly precipitation (cm)
MP_AUG	Mean August monthly precipitation (cm)
MP_SEP	Mean September monthly precipitation (cm)
MP_OCT	Mean October monthly precipitation (cm)
MP_NOV	Mean November monthly precipitation (cm)
MP_DEC	Mean December monthly precipitation (cm)
	Ecologic/hydrologic regions characteristics (scale 1:1,000,00–1:7,500,000)
ECO_XXX	Percentage of basin in USEPA Ecoregion XXX
HL_XXX	Percentage of basin in hydrologic landscape region XXX
	Infrastructure characteristics (scale 1:100,000)
RDLENGTH	Road network length in watershed (km)
ROADDEN	Road density in watershed = (RDLENGTH divided by watershed area [km^2])
RDARDEN	Road area index density. Road length multiplied by an area factor (by type of road)(km/km^2)
RDTRDEN	Road traffic index density. Road length multiplied by a traffic factor (by type of road) (km/km^2)
RDAREAINDX	Road area index in watershed (weighted miles): road area $index_i = SUM_j (length_{ij} \times Sfc\_Area\_Wt_{ij})$ for watershed I and CFCC TIGER code j
RDTRAFINDX	Road traffic index in watershed (weighted miles): road traffic $index_i = SUM_j (length_{ij} \times Veh\_Traffic\_Wt_{ij})$ for watershed I and CFCC TIGER code j
D_PSCOUNT	Density (no./100 km^2) of point source dischargers in watershed (WPDES database)
D_TRICOUNT	Density (no./100 km^2) of Toxics Release Inventory sites in watershed
D_DAMCOUNT	Density (no./100 km^2) of dams in watershed (WDNR Dam Safety database)
	Land-cover characteristics, 2001, basin (30-m resolution)
P_NLCD1_1	Aggregated NLCD 2001 level 1 category: water (percentage of watershed)
P_NLCD1_2	Aggregated NLCD 2001 level 1 category: developed (percentage of watershed)
P_NLCD1_3	Aggregated NLCD 2001 level 1 category: barren (percentage of watershed)
P_NLCD1_4	Aggregated NLCD 2001 level 1 category: forest (percentage of watershed)
P_NLCD1_5	Aggregated NLCD 2001 level 1 category: shrubland (percentage of watershed)
P_NLCD1_7	Aggregated NLCD 2001 level 1 category: herbaceous natural vegetation (percentage of watershed)
P_NLCD1_8	Aggregated NLCD 2001 level 1 category: crops and pasture (percentage of watershed)

Appendix 1–2. Geographic information system (GIS) derived characteristics for 30 sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[km^2, square kilometer; km, kilometer; cm, centimeter; m, meter; m/km, meter per kilometer; °C, degrees Celsius; ha, hectacres; g/m^2, gram per square meter; cm/cm, centimeter per centimeter; mm, millimeter; %, percent; <, less than; >, greater than; CFCC, census feature class code; TIGER, Topologically Integrated Geographic Encoding and Referencing; USEPA, U.S. Environmental Protection Agency; WPDES, Wisconsin Pollutant Discharge Elimination System; WDNR; Wisconsin Department of Natural Resources; NLCD, National Land Cover Database; MRLC, Multi-Resolution Land Characteristics Consortium; USDA, U.S. Department of Agriculture]

Characteristic abbreviation	Definition
P_NLCD1_9	Aggregated NLCD 2001 level 1 category: wetlands (percentage of watershed)
P_NLCD_4+9	Aggregated NLCD 2001 level 1 category: sum of forest and wetlands (percentage of watershed)
PNLCD_11	Percent watershed area, watershed area in NLCD 2001,Water, Open Water
PNLCD_21	Percent watershed area, watershed area in NLCD 2001, Developed, Open Space
PNLCD_22	Percent watershed area, Watershed area in NLCD 2001, Developed, Low Intensity
PNLCD_23	Percent watershed area, Watershed area in NLCD 2001, Developed, Medium Intensity
PNLCD_24	Percent watershed area, Watershed area in NLCD 2001, Developed, High Intensity
PNLCD_31	Percent watershed area, Watershed area in NLCD 2001, Barren, (Rock/Clay/Sand)
PNLCD_41	Percent watershed area, Watershed area in NLCD 2001, Forest, Deciduous Forest
PNLCD_42	Percent watershed area, Watershed area in NLCD 2001, Forest, Evergreen Forest
PNLCD_43	Percent watershed area, Watershed area in NLCD 2001, Forest, Mixed Forest
PNLCD_52	Percent watershed area, Watershed area in NLCD 2001, Shrubland, Shrub/Scrub
PNLCD_71	Percent watershed area, Watershed area in NLCD 2001, herbaceous upland natural/semi-natural vegetation, Grasslands/Herbaceous
PNLCD_81	Percent watershed area, Watershed area in NLCD 2001, herbaceous planted/cultivated, Pasture/Hay
PNLCD_82	Percent watershed area, Watershed area in NLCD 2001, herbaceous planted/cultivated, Cultivated Crops
PNLCD_90	Percent watershed area, Watershed area in NLCD 2001, Wetlands, Woody Wetlands
PNLCD_95	Percent watershed area, Watershed area in NLCD 2001, Wetlands, Emergent Herbaceous Wetlands
NLCD_IS	NLCD 2001 mean percent impervious surface (percentage of watershed) (based on 30-m resolution data)
	Land-cover characteristics, 2001, 100-meter riparian zone (30-m resolution)
P_NLCD1_B1	Buffer area in aggregated NLCD 2001 level 1 category: water (percentage of buffer area)
P_NLCD1_B2	Buffer area in aggregated NLCD 2001 level 1 category: developed (percentage of buffer area)
P_NLCD1_B3	Buffer area in aggregated NLCD 2001 level 1 category: barren (percentage of buffer area)
P_NLCD1_B4	Buffer area in aggregated NLCD 2001 level 1 category: forest (percentage of buffer area)
P_NLCD1_B5	Buffer area in aggregated NLCD 2001 level 1 category: shrubland (percentage of buffer area)
P_NLCD1_B7	Buffer area in aggregated NLCD 2001 level 1 category: herbaceous natural vegetation (percentage of buffer area)
P_NLCD1_B8	Buffer area in aggregated NLCD 2001 level 1 category: crops and pasture (percentage of buffer area)
P_NLCD1_B9	Buffer area in aggregated NLCD 2001 level 1 category: wetlands (percentage of buffer area)
NLCD_BIS	NLCD 2001 mean percent impervious surface within buffer area (percentage of buffer area)
P_NLCD_B4+B9	Buffer area in aggregated NLCD 2001 level 1 category: sum of forest and wetlands (percentage of buffer area)

Appendix 1–2. Geographic information system (GIS) derived characteristics for 30 sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[km^2, square kilometer; km, kilometer; cm, centimeter; m, meter; m/km, meter per kilometer; °C, degrees Celsius; ha, hectacres; g/m^2, gram per square meter; cm/cm, centimeter per centimeter; mm, millimeter; %, percent; <, less than; >, greater than; CFCC, census feature class code; TIGER, Topologically Integrated Geographic Encoding and Referencing; USEPA, U.S. Environmental Protection Agency; WPDES, Wisconsin Pollutant Discharge Elimination System; WDNR; Wisconsin Department of Natural Resources; NLCD, National Land Cover Database; MRLC, Multi-Resolution Land Characteristics Consortium; USDA, U.S. Department of Agriculture]

Characteristic abbreviation	Definition
	Land-cover characteristics, 2001, segment data (30-m resolution)
NLCD_S11	Percent NLCD 2001,Water, Open Water in stream segment buffer (90 m on each side of stream; Stream is an additional 30-m cell)
NLCD_S12	Percent NLCD 2001, Water, Perennial Ice/Snow in stream segment buffer (90 m on each side of stream)
NLCD_S21	Percent NLCD 2001, Developed, Open Space in stream segment buffer (90 m on each side of stream; Stream is an additional 30-m cell)
NLCD_S22	Percent NLCD 2001, Developed, Low Intensity in stream segment buffer (90 m on each side of stream; Stream is an additional 30-m cell)
NLCD_S23	Percent NLCD 2001, Developed, Medium Intensity in stream segment buffer (90 m on each side of stream; Stream is an additional 30-m cell)
NLCD_S24	Percent NLCD 2001, Developed, High Intensity in stream segment buffer (90 m on each side of stream; Stream is an additional 30-m cell)
NLCD_S31	Percent NLCD 2001, Barren, (Rock/Clay/Sand) in stream segment buffer (90 m on each side of stream; Stream is an additional 30-m cell)
NLCD_S32	Percent NLCD 2001, Barren, Unconsolidated shore in stream segment buffer (90 m on each side of stream; Stream is an additional 30-m cell)
NLCD_S41	Percent NLCD 2001, Forest, Deciduous Forest in stream segment buffer (90 m on each side of stream; Stream is an additional 30-m cell)
NLCD_S42	Percent NLCD 2001, Forest, Evergreen Forest in stream segment buffer (90 m on each side of stream; Stream is an additional 30-m cell)
NLCD_S43	Percent NLCD 2001, Forest, Mixed Forest in stream segment buffer (90 m on each side of stream; Stream is an additional 30-m cell)
NLCD_S52	Percent NLCD 2001, Shrubland, Shrub/Scrub in stream segment buffer (90 m on each side of stream; Stream is an additional 30-m cell)
NLCD_S71	Percent NLCD 2001, herbaceous upland natural/semi-natural vegetation, Grasslands/Herbaceous in stream segment buffer (90 m on each side of stream; Stream is an additional 30-m cell)
NLCD_S81	Percent NLCD 2001, herbaceous planted/cultivated, Pasture/Hay in stream segment buffer (90 m on each side of stream; Stream is an additional 30-m cell)
NLCD_S82	Percent NLCD 2001, herbaceous planted/cultivated, Cultivated Crops in stream segment buffer (90 m on each side of stream; Stream is an additional 30-m cell)
NLCD_S90	Percent NLCD 2001, Wetlands, Woody Wetlands in stream segment buffer (90 m on each side of stream; Stream is an additional 30-m cell)
NLCD_S91	Percent NLCD 2001, Wetlands, Woody Wetlands, Palustrine Forested Wetland in stream segment buffer (90 m on each side of stream; Stream is an additional 30-m cell)
NLCD_S92	Percent NLCD 2001, Wetlands,Woody Wetlands, Palustrine Scrub/Shrub Wetland in stream segment buffer (90 m on each side of stream; Stream is an additional 30-m cell)

Appendix 1–2. Geographic information system (GIS) derived characteristics for 30 sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[km^2, square kilometer; km, kilometer; cm, centimeter; m, meter; m/km, meter per kilometer; °C, degrees Celsius; ha, hectacres; g/m^2, gram per square meter; cm/cm, centimeter per centimeter; mm, millimeter; %, percent; <, less than; >, greater than; CFCC, census feature class code; TIGER, Topologically Integrated Geographic Encoding and Referencing; USEPA, U.S. Environmental Protection Agency; WPDES, Wisconsin Pollutant Discharge Elimination System; WDNR; Wisconsin Department of Natural Resources; NLCD, National Land Cover Database; MRLC, Multi-Resolution Land Characteristics Consortium; USDA, U.S. Department of Agriculture]

Characteristic abbreviation	Definition
NLCD_S95	Percent NLCD 2001, Wetlands, Emergent Herbaceous Wetlands in stream segment buffer (90 m on each side of stream; Stream is an additional 30-m cell)
NLCD_S96	Percent NLCD 2001, Wetlands, Emergent Herbaceous Wetlands, Palustrine Emergent Wetland (Persistent) in stream segment buffer (90 m on each side of stream; Stream is an additional 30-m cell)
NLCD_S97	Percent NLCD 2001, Wetlands, Emergent Herbaceous Wetlands, Estuarine Emergent Wetland in stream segment buffer (90 m on each side of stream; Stream is an additional 30-m cell)
NLCD_S98	Percent NLCD 2001, Wetlands, Emergent Herbaceous Wetlands, Palustrine Aquatic Bed in stream segment buffer (90 m on each side of stream; Stream is an additional 30-m cell)
NLCD_S99	Percent NLCD 2001, Wetlands, Emergent Herbaceous Wetlands, Estuarine Aquatic Bed in stream segment buffer (90 m on each side of stream; Stream is an additional 30-m cell)
Segment characteristics (30-m resolution)	
SEGCUR	Curvilinear stream length of calculated segment (m)
SEG_RSX	Number of road-stream intersections per stream segment
SEG_RSXK	Number of road-stream intersections per stream segment kilometer
SEG_RMD	Mean distance from stream segment to nearest road (m)
SINUOS	Segment sinuosity: curvilinear length between endpoints divided by straight length
SEG_GRAD	Segment gradient (m/km): elevation difference between endpoints divided by curvilinear length
pWATERseg	Aggregated NLCD 2001 level 1: water (percent segment riparian area)
pURBANseg	Aggregated NLCD 2001 level 1: developed (percent segment riparian area)
pBARRENseg	Aggregated NLCD 2001 level 1: barren (percent segment riparian area)
pFORESTseg	Aggregated NLCD 2001 level 1: forest (percent segment riparian area)
pRANGEseg	Aggregated NLCD 2001 level 1: shrubland (percent segment riparian area)
pHERBACseg	Aggregated NLCD 2001 level 1: herbaceous natural vegetation (percent segment riparian area)
pAGseg	Aggregated NLCD 2001 level 1: crops and pasture (percent segment riparian area)
pWETLseg	Aggregated NLCD 2001 level 1: wetlands (percent segment riparian area)
Land-cover characteristics, 2001, distance-weighted (30-m resolution)	
pWATERdw	Aggregated NLCD01 level 1: water (percent basin area, weighted by distance from sampling site)
pURBANdw	Aggregated NLCD01 level 1: developed (percent basin area, weighted by distance from sampling site)
pBARRENdw	Aggregated NLCD01 level 1: barren (percent basin area, weighted by distance from sampling site)
pFORESTdw	Aggregated NLCD01 level 1: forest (percent basin area, weighted by distance from sampling site)
pRANGEdw	Aggregated NLCD01 level 1: shrubland (percent basin area, weighted by distance from sampling site)

Appendix 1–2. Geographic information system (GIS) derived characteristics for 30 sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[km^2, square kilometer; km, kilometer; cm, centimeter; m, meter; m/km, meter per kilometer; °C, degrees Celsius; ha, hectacres; g/m^2, gram per square meter; cm/cm, centimeter per centimeter; mm, millimeter; %, percent; <, less than; >, greater than; CFCC, census feature class code; TIGER, Topologically Integrated Geographic Encoding and Referencing; USEPA, U.S. Environmental Protection Agency; WPDES, Wisconsin Pollutant Discharge Elimination System; WDNR; Wisconsin Department of Natural Resources; NLCD, National Land Cover Database; MRLC, Multi-Resolution Land Characteristics Consortium; USDA, U.S. Department of Agriculture]

Characteristic abbreviation	Definition
pHERBACdw	Aggregated NLCD01 level 1: herbaceous vegetation (percent basin area, weighted by distance from sampling site)
pAGdw	Aggregated NLCD01 level 1: crops/pasture (percent basin area, weighted by distance from sampling site)
pWETLdw	Aggregated NLCD01 level 1: wetlands (percent basin area, weighted by distance from sampling site)
pFORESTdw + pWETLdw	Aggregated NLCD01 level 1: sum of forest and wetlands (percent basin area, weighted by distance from sampling site)
PWNLCD_11	NLCD 2001 level 2 category: water, open water (percent basin area, weighted by distance from sampling site)
pwNLCD_21	NLCD 2001 level 2 category: Developed, Open Space (percent basin area, weighted by distance from sampling site)
pwNLCD_22	NLCD 2001 level 2 category: Developed, Low Intensity (percent basin area, weighted by distance from sampling site)
pwNLCD_23	NLCD 2001 level 2 category: Developed, Medium Intensity (percent basin area, weighted by distance from sampling site)
pwNLCD_24	NLCD 2001 level 2 category: Developed, High Intensity (percent basin area, weighted by distance from sampling site)
pwNLCD_31	NLCD 2001 level 2 category: Barren, (Rock/Clay/Sand) (percent basin area, weighted by distance from sampling site)
pwNLCD_41	NLCD 2001 level 2 category: Forest, Deciduous Forest (percent basin area, weighted by distance from sampling site)
pwNLCD_42	NLCD 2001 level 2 category: Forest, Evergreen Forest (percent basin area, weighted by distance from sampling site)
pwNLCD_43	NLCD 2001 level 2 category: Forest, Mixed Forest (percent basin area, weighted by distance from sampling site)
pwNLCD_52	NLCD 2001 level 2 category: Shrubland, Shrub/Scrub (percent basin area, weighted by distance from sampling site)
pwNLCD_71	NLCD 2001 level 2 category: herbaceous upland natural/semi-natural vegetation, Grasslands/Herbaceous (percent basin area, weighted by distance from sampling site)
pwNLCD_81	NLCD 2001 level 2 category: herbaceous planted/cultivated, Pasture/Hay (percent basin area, weighted by distance from sampling site)
pwNLCD_82	NLCD 2001 level 2 category: herbaceous planted/cultivated, Cultivated Crops (percent basin area, weighted by distance from sampling site)
pwNLCD_90	NLCD 2001 level 2 category: Wetlands, Woody Wetlands (percent basin area, weighted by distance from sampling site)
pwNLCD_95	NLCD 2001 level 2 category: Wetlands, Emergent Herbaceous Wetlands (percent basin area, weighted by distance from sampling site)

Appendix 1–2. Geographic information system (GIS) derived characteristics for 30 sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[km^2, square kilometer; km, kilometer; cm, centimeter; m, meter; m/km, meter per kilometer; °C, degrees Celsius; ha, hectacres; g/m^2, gram per square meter; cm/cm, centimeter per centimeter; mm, millimeter; %, percent; <, less than; >, greater than; CFCC, census feature class code; TIGER, Topologically Integrated Geographic Encoding and Referencing; USEPA, U.S. Environmental Protection Agency; WPDES, Wisconsin Pollutant Discharge Elimination System; WDNR; Wisconsin Department of Natural Resources; NLCD, National Land Cover Database; MRLC, Multi-Resolution Land Characteristics Consortium; USDA, U.S. Department of Agriculture]

Characteristic abbreviation	Definition
	Land-cover characteristics, 1992, basin (30-m resolution)
P_MRLC_1	Aggregated MRLC 1992 level 1: water (percentage of watershed)
P_MRLC_2	Aggregated MRLC 1992 level 1: developed (percentage of watershed)
P_MRLC_3	Aggregated MRLC 1992 level 1: barren/transitional (percentage of watershed)
P_MRLC_4	Aggregated MRLC 1992 level 1: forest (percentage of watershed)
P_MRLC_5	Aggregated MRLC 1992 level 1: shrubland (percentage of watershed)
P_MRLC_6	Aggregated MRLC 1992 level 1: orchard (percentage of watershed)
P_MRLC_7	Aggregated MRLC 1992 level 1: herbaceous natural vegetation (percentage of watershed)
P_MRLC_8	Aggregated MRLC 1992 level 1: crops and pasture (percentage of watershed)
P_MRLC_9	Aggregated MRLC 1992 level 1: wetlands (percentage of watershed)
	Landscape pattern characteristics (30-m resolution) Analysis conducted with seven classes (classes comprised of the seven NLCD 2001 level 1 categories).
BAS_SHAP_INDX	Measure of the basin shape/compactness of the entire watershed boundary (unitless)
NP_C1	Number of patches, NLCD 2001 level 1 category: water.
PD_C1	Patch density, NLCD 2001 level 1 category: water. (number of patches/100 hectares)
LPI_C1	Largest patch index, NLCD 2001 level 1 category: water. Percentage of basin area composed of the largest patch of that class (%).
PAM_C1	Mean patch area, NLCD 2001 level 1 category: water. Mean patch area for that class (ha).
SIM_C1	Shape index, mean, NLCD 2001 level 1 category: water. Measure of mean patch shape/compactness.
PIM_C1	Proximity index, mean, NLCD 2001 level 1 category: water. Measure of isolation and fragmentation of patches (unitless).
EDM_C1	Euclidean nearest neighbor distance, mean, NLCD 2001 level 1 category: water. Mean nearest neighbor distance for patches comprising the class (m). Measure of how dispersed the patches are.
PLA_C1	Proportion of like adjacencies, NLCD 2001 level 1 category: water. Percentage of patch adjacencies that are of the same type (%)
NP_C2	Number of patches, NLCD 2001 level 1 category: developed.
PD_C2	Patch density, NLCD 2001 level 1 category: developed. Number of patches/100 hectares
LPI_C2	Largest patch index, NLCD 2001 level 1 category: developed. Percentage of basin area composed of the largest patch of that class (%).
PAM_C2	Mean patch area, NLCD 2001 level 1 category: developed. Mean patch area for that class (ha).
SIM_C2	Shape index, mean, NLCD 2001 level 1 category: developed. Measure of mean patch shape/compactness.

Appendix 1–2. Geographic information system (GIS) derived characteristics for 30 sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[km^2, square kilometer; km, kilometer; cm, centimeter; m, meter; m/km, meter per kilometer; °C, degrees Celsius; ha, hectacres; g/m^2, gram per square meter; cm/cm, centimeter per centimeter; mm, millimeter; %, percent; <, less than; >, greater than; CFCC, census feature class code; TIGER, Topologically Integrated Geographic Encoding and Referencing; USEPA, U.S. Environmental Protection Agency; WPDES, Wisconsin Pollutant Discharge Elimination System; WDNR; Wisconsin Department of Natural Resources; NLCD, National Land Cover Database; MRLC, Multi-Resolution Land Characteristics Consortium; USDA, U.S. Department of Agriculture]

Characteristic abbreviation	Definition
PIM_C2	Proximity index, mean, NLCD 2001 level 1 category: developed. Measure of isolation and fragmentation of patches (unitless).
EDM_C2	Euclidean nearest neighbor distance, mean, NLCD 2001 level 1 category: developed. Mean nearest neighbor distance for patches comprising the class (m). Measure of how dispersed the patches are.
PLA_C2	Percentage of like adjacencies, NLCD 2001 level 1 category: developed. Percentage of patch adjacencies that are of the same type (%).
NP_C3	Number of patches, NLCD 2001 level 1 category: barren.
PD_C3	Patch density, NLCD 2001 level 1 category: barren. (number of patches/100 hectares)
LPI_C3	Largest patch index, NLCD 2001 level 1 category: barren. Percentage of basin area composed of the largest patch of that class (%).
PAM_C3	Mean patch area, NLCD 2001 level 1 category: barren. Mean patch area for that class (ha)
SIM_C3	Shape index, mean, NLCD 2001 level 1 category: barren. Measure of mean patch shape/compactness.
PIM_C3	Proximity index, mean, NLCD 2001 level 1 category: barren. Measure of isolation and fragmentation of patches (unitless)
EDM_C3	Euclidean nearest neighbor distance, mean, NLCD 2001 level 1 category: barren. Mean nearest neighbor distance for patches comprising the class (m). Measure of how dispersed the patches are.
PLA_C3	Percentage of like adjacencies, NLCD 2001 level 1 category: barren. Percentage of patch adjacencies that are of the same type (%).
NP_C4	Number of patches, NLCD 2001 level 1 category: forest.
PD_C4	Patch density, NLCD 2001 level 1 category: forest. (number of patches/100 hectares)
LPI_C4	Largest patch index, NLCD 2001 level 1 category: forest. Percentage of basin area composed of the largest patch of that class (%).
PAM_C4	Mean patch area, NLCD 2001 level 1 category: forest. Mean patch area for that class (ha)
SIM_C4	Shape index, mean, NLCD 2001 level 1 category: forest. Measure of mean patch shape/compactness.
PIM_C4	Proximity index, mean, NLCD 2001 level 1 category: forest. Measure of isolation and fragmentation of patches (unitless).
EDM_C4	Euclidean nearest neighbor distance, mean, NLCD 2001 level 1 category: forest. Mean nearest neighbor distance for patches comprising the class (m). Measure of how dispersed the patches are.
PLA_C4	Percentage of like adjacencies, NLCD 2001 level 1 category: forest. Percentage of patch adjacencies that are of the same type (%).
NP_C5	Number of patches, NLCD 2001 level 1 category: shrubland/grassland.
PD_C5	Patch density, NLCD 2001 level 1 category: shrubland/grassland. (number of patches/100 hectares)
LPI_C5	Largest patch index, NLCD 2001 level 1 category: shrubland/grassland. Percentage of basin area composed of the largest patch of that class (%).

Appendix 1–2. Geographic information system (GIS) derived characteristics for 30 sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[km^2, square kilometer; km, kilometer; cm, centimeter; m, meter; m/km, meter per kilometer; °C, degrees Celsius; ha, hectacres; g/m^2, gram per square meter; cm/cm, centimeter per centimeter; mm, millimeter; %, percent; <, less than; >, greater than; CFCC, census feature class code; TIGER, Topologically Integrated Geographic Encoding and Referencing; USEPA, U.S. Environmental Protection Agency; WPDES, Wisconsin Pollutant Discharge Elimination System; WDNR; Wisconsin Department of Natural Resources; NLCD, National Land Cover Database; MRLC, Multi-Resolution Land Characteristics Consortium; USDA, U.S. Department of Agriculture]

Characteristic abbreviation	Definition
PAM_C5	Mean patch area, NLCD 2001 level 1 category: shrubland/grassland. Mean patch area for that class (ha).
SIM_C5	Shape index, mean, NLCD 2001 level 1 category: shrubland/grassland. Measure of mean patch shape/compactness.
PIM_C5	Proximity index, mean, NLCD 2001 level 1 category: shrubland/grassland. Measure of isolation and fragmentation of patches (unitless).
EDM_C5	Euclidean nearest neighbor distance, mean, NLCD 2001 level 1 category: shrubland/grassland. Mean nearest neighbor distance for patches comprising the class (m). Measure of how dispersed the patches are.
PLA_C5	Percentage of like adjacencies, NLCD 2001 level 1 category: shrubland/grassland. Percentage of patch adjacencies that are of the same type (%).
NP_C8	Number of patches, NLCD 2001 level 1 category: agriculture.
PD_C8	Patch density, NLCD 2001 level 1 category: agriculture. (number of patches/100 hectares)
LPI_C8	Largest patch index, NLCD 2001 level 1 category: agriculture. Percentage of basin area composed of the largest patch of that class (%).
PAM_C8	Mean patch area, NLCD 2001 level 1 category: agriculture. Mean patch area for that class (ha).
SIM_C8	Shape index, mean, NLCD 2001 level 1 category: agriculture. Measure of mean patch shape/compactness.
PIM_C8	Proximity index, mean, NLCD 2001 level 1 category: agriculture. Measure of isolation and fragmentation of patches (unitless).
EDM_C8	Euclidean nearest neighbor distance, mean, NLCD 2001 level 1 category: agriculture. Mean nearest neighbor distance for patches comprising the class (m). Measure of how dispersed the patches are.
PLA_C8	Percentage of like adjacencies, NLCD 2001 level 1 category: agriculture. Percentage of patch adjacencies that are of the same type (%).
NP_C9	Number of patches, NLCD 2001 level 1 category: wetland.
PD_C9	Patch density, NLCD 2001 level 1 category: wetland (number of patches/100 hectares).
LPI_C9	Largest patch index, NLCD 2001 level 1 category: wetland. Percentage of basin area composed of the largest patch of that class (%).
PAM_C9	Mean patch area, NLCD 2001 level 1 category: wetland. Mean patch area for that class (ha).
SIM_C9	Shape index, mean, NLCD 2001 level 1 category: wetland. Measure of mean patch shape/compactness.
PIM_C9	Proximity index, mean, NLCD 2001 level 1 category: wetland. Measure of isolation and fragmentation of patches (unitless).
EDM_C9	Euclidean nearest neighbor distance, NLCD 2001 level 1 category: wetland. Mean nearest neighbor distance for patches comprising the class (m). Measure of how dispersed the patches are.
PLA_C9	Percentage of like adjacencies, NLCD 2001 level 1 category: wetland. Percentage of patch adjacencies that are of the same type (%).
NP_C4 + NP_C9	Number of patches, NLCD 2001 level 1 category: sum of forest and wetland categories.
PLA_C4 + PLA_C9	Percentage of like adjacencies, NLCD 2001 level 1 category: sum of forest and wetland categories. Percentage of patch adjacencies that are of the same type (%).

Appendix 1–2. Geographic information system (GIS) derived characteristics for 30 sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[km^2, square kilometer; km, kilometer; cm, centimeter; m, meter; m/km, meter per kilometer; °C, degrees Celsius; ha, hectacres; g/m^2, gram per square meter; cm/cm, centimeter per centimeter; mm, millimeter; %, percent; <, less than; >, greater than; CFCC, census feature class code; TIGER, Topologically Integrated Geographic Encoding and Referencing; USEPA, U.S. Environmental Protection Agency; WPDES, Wisconsin Pollutant Discharge Elimination System; WDNR; Wisconsin Department of Natural Resources; NLCD, National Land Cover Database; MRLC, Multi-Resolution Land Characteristics Consortium; USDA, U.S. Department of Agriculture]

Characteristic abbreviation	Definition
	Landscape pattern characteristics (30-m resolution) Analysis conducted with two classes: urban (NLCD 2001 level 1 developed) and non-urban (remaining six NLCD 2001 level 1 categories)
NP_U	Number of patches: urban.
PD_U	Patch density: urban (number of patches/100 hectares).
LPI_U	Largest patch index: urban. Percentage of basin area composed of the largest patch of that class (%).
PAM_U	Mean patch area: ubran. Mean patch area for that class (ha).
SIM_U	Shape index, mean: urban. Measure of mean patch shape/compactness.
SICV_U	Shape index, coefficient of variance: urban.
PIM_U	Proximity index, mean: urban. Measure of isolation and fragmentation of patches (unitless).
PICV_U	Proximity index, coefficient of variance: urban.
EDM_U	Euclidean nearest neighbor distance, mean: urban. Mean nearest neighbor distance for patches comprising the class (m). Measure of how dispersed the patches are.
EDCV_U	Euclidean nearest neighbor distance, coefficient of variance: urban.
PLA_U	Percentage of like adjacencies: urban. Percentage of patch adjacencies that are of the same type (%).
NP_NU	Number of patches: non-urban.
PD_NU	Patch density: non-urban (number of patches/100 hectares).
LPI_NU	Largest patch index: non-urban. Percentage of basin area composed of the largest patch of that class (%).
PAM_NU	Mean patch area: non-ubran. Mean patch area for that class (ha).
SIM_NU	Shape index, mean: non-urban. Measure of mean patch shape/compactness.
SICV_NU	Shape index, coefficient of variance: non-urban.
PIM_NU	Proximity index, mean: non-urban. Measure of isolation and fragmentation of patches (unitless).
PICV_NU	Proximity index, coefficient of variance: non-urban.
EDM_NU	Euclidean nearest neighbor distance, mean: non-urban. Mean nearest neighbor distance for patches comprising the class (m). Measure of how dispersed the patches are.
EDCV_NU	Euclidean nearest neighbor distance, coefficient of variance: non-urban.
PLA_NU	Percentage of like adjacencies: non-urban. Percentage of patch adjacencies that are of the same type (%).
	Soils characteristic (scale 1:250,000–1:1,000,000)
AWCH	Mean high-range available water capacity (cm/cm)
AWCL	Mean low-range available water capacity (cm/cm)
CLYAVE	Mean percent clay (percent)
CLYH	Mean high range percent clay (percent)
CLYL	Mean low range percent clay (percent)
KFCAVE	Mean soil erodibiity factor (K factor) including rock fragments (unitless)
KFCH	Mean high-range soil erodibiity factor (K factor) including rock fragments (unitless)

Appendix 1–2. Geographic information system (GIS) derived characteristics for 30 sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[km^2, square kilometer; km, kilometer; cm, centimeter; m, meter; m/km, meter per kilometer; °C, degrees Celsius; ha, hectacres; g/m^2, gram per square meter; cm/cm, centimeter per centimeter; mm, millimeter; %, percent; <, less than; >, greater than; CFCC, census feature class code; TIGER, Topologically Integrated Geographic Encoding and Referencing; USEPA, U.S. Environmental Protection Agency; WPDES, Wisconsin Pollutant Discharge Elimination System; WDNR; Wisconsin Department of Natural Resources; NLCD, National Land Cover Database; MRLC, Multi-Resolution Land Characteristics Consortium; USDA, U.S. Department of Agriculture]

Characteristic abbreviation	Definition
KFCL	Mean low-range soil erodibility factor (K factor) including rock fragments (unitless)
ORMH	Mean high-range organic matter (percent)
ORML	Mean low-range organic matter (percent)
PERH	Mean high-range permeability (cm/h)
PERL	Mean low-range permeability (cm/h)
P_TEXTURE0	Water (percentage of watershed)
P_TEXTURE1	Simplified USDA soil texture classification (Shirazi): coarse (percentage of watershed)
P_TEXTURE2	Simplified USDA soil texture classification (Shirazi): moderately coarse (percentage of watershed)
P_TEXTURE3	Simplified USDA soil texture classification (Shirazi): medium coarse (percentage of watershed)
P_TEXTURE4	Simplified USDA soil texture classification (Shirazi): moderately fine (percentage of watershed)
P_TEXTURE5	Simplified USDA soil texture classification (Shirazi): fine (percentage of watershed)
P_HSG_1	Hydrologic soil group A: minimum infiltration rate 8–12 mm per hour (percentage of watershed)
P_HSG_2	Hydrologic soil group B: minimum infiltration rate 4–8 mm per hour (percentage of watershed)
P_HSG_3	Hydrologic soil group C: minimum infiltration rate 1–4 mm per hour (percentage of watershed)
P_HSG_4	Hydrologic soil group D: minimum infiltration rate 0–1 mm per hour (percentage of watershed)
P_HSG_5	Hydrologic soil group: water (percentage of watershed)
SNDH	Mean high-range sand (percent)
SNDL	Mean low-range sand (percent)
WTDH	Mean high-range depth to water table (m)
WTDL	Mean low-range depth to water table (m)
SOC100CM	Soil organic carbon, first 100-centimeter soil depth (g/m^2)
SOCM30CM	Soil organic carbon, first 30-centimeter soil depth (g/m^2)
PSRF2	Texture of surficial deposits—sand (percentage of watershed)
	Topography (Scale 1:24,000–1:100,000)
MIN_ELEV	Minimum watershed elevation (m)
MAX_ELEV	Maximum watershed elevation (m)
MEANELEV	Mean watershed elevation (m)
RELIEF	Watershed relief (maximum minus minimum elevation) (m)
MIDPOINT	Midpoint elevation, calculated as the sum of minimum elevation and relief divided by 2
PFLATLOW	Percentage of watershed area that is flat (slope less than 1 percent) and low (elevation < midpoint)
P_FLATUP	Percentage of watershed area that is flat (slope less than 1 percent) and upland (elevation > midpoint)
P_FLAT	Percentage of watershed area that is flat (slope less than 1 percent)
SLOPE_X	Mean watershed slope (percent)
WET_MEAN	Mean value of wetness index across all cells in watershed
WET_STD	Standard deviation of wetness index across all cells in watershed

Appendix 1-3. Characteristics used to calculate urban intensity index (UII) with rho values for sites in the Milwaukee to Green Bay, Wis., study area. Spearman rank correlations are shown for relations between site-selection characteristics and drainage area and 2000 population density.

[km^2, square kilometer; persons/km^2, persons per square kilometer; %, percent; m, meter; NLCD, National Land Coverage Database; CFCC, census feature class code; TIGER, Topologically Integrated Geographic Encoding and Referencing; PCA, principal component analysis]

Characteristic abbreviation	Definition	Watershed area (rho value)	2000 Population density (rho value)
	Land-cover characteristics (watershed)		
P_NLCD1_2	Aggregated NLCD 2001 level 1 category: developed (% of watershed)	-0.47	0.98
P_NLCD1_5	Aggregated NLCD 2001 level 1 category: shrubland (% of watershed)	-.24	.73
P_NLCD1_8	Aggregated NLCD 2001 level 1 category: crops and pasture (% of watershed)	.45	-.86
NLCD_IS	NLCD 2001 mean percentage of impervious surface, based on 30-m resolution data (% of watershed)	-.43	.97
	Land-cover characteristics (100-m buffer)		
P_NLCD1_B5	Buffer area in aggregated NLCD 2001 level 1 category: shrubland (% of watershed)	-.45	.75
P_NLCD1_B8	Buffer area in aggregated NLCD 2001 level 1 category: crops and pasture (% of watershed)	.47	-.82
NLCD_BIS	NLCD 2001 mean percentage of impervious surface within buffer area (% of watershed)	-.43	.93
	Infrastructure characteristics		
RDAREAINDX	Road area index in watershed (weighted miles): road area index$_i$ = SUM$_j$ (length$_{ij}$ × Sfc_Area_Wt$_{ij}$) for watershed I and CFCC TIGER code j	.31	.59
RDTRAFINDX	Road traffic index in watershed (weighted miles): road traffic index$_i$ = SUM$_j$ (length$_{ij}$ × Veh_Traffic_Wt$_{ij}$) for watershed I and CFCC TIGER code j	.33	.58
	2000 Census characteristics		
SEI_2	Socioeconomic index 2 (PCA analysis—strongly weighted on variables that reflect large, rural households using propane gas and wood as fuel, and high percentage of population with high-school degree)	.47	-.90
SEI_4	Socioeconomic index 4 (PCA analysis—strongly weighted on variables that reflect relatively new housing units and larger households using utility gas as fuel)	-.47	.73
HHDEN	Household density (occupied housing units per square kilometer) (block-group based)	-.43	.99
HUDEN	Density of housing units (housing units/square kilometer) (block-group based)	-.44	.99
PPURBAN	Percentage of population living in urban area (block-group based)	-.49	.95
PPRURAL	Percentage of population living in rural area (block-group based)	.47	-.95
PPWHITE	Percentage of population race who are white (block-group based)	.36	-.80
PPBLACK	Percentage of population race who are black (block-group based)	-.13	.75
PPASIA	Percentage of population race who are Asian (block-group based)	-.48	.84
PPMALE	Percentage of population who are male (block-group based)	.43	-.60
PPFEMALE	Percentage of population who are female (block-group based)	-.42	.59

Appendix 1-3. Characteristics used to calculate urban intensity index (UII) with rho values for sites in the Milwaukee to Green Bay, Wis., study area—Continued. Spearman rank correlations are shown for relations between site-selection characteristics and drainage area and 2000 population density.

[km^2, square kilometer; persons/km^2, persons per square kilometer; %, percent; m, meter; NLCD, National Land Coverage Database; CFCC, census feature class code; TIGER, Topologically Integrated Geographic Encoding and Referencing; PCA, principal component analysis]

Characteristic abbreviation	Definition	Watershed area (rho value)	2000 Population density (rho value)
	2000 Census characteristics (continued)		
PC_US	Percentage of citizens born in U.S. (block-group based)	0.36	-0.80
PC_INSTAT	Percentage of citizens born in State of residence (block-group based)	.40	-.79
PC_OUTSTAT	Percentage of citizens born in other States in the U.S. (block-group based)	-.41	.72
PC_NONUS	Percentage of population who were born outside the U.S. (block-group based)	-.23	.67
PP_SH95	Percentage of population living in same house as in 1995 (block-group based)	.35	-.78
PHS_G25	Percentage of population greater than 25 years old who have high school degrees (block- group based)	.47	-.82
PBCH_G25	Percentage of population greater than 25 years old who have bachelor's degrees (block-group based)	-.36	.59
PF_GT16E	Percentage of female population greater than 16 years of age who are employed (block-group based)	.26	-.52
P_OWN	Percentage of total housing units that are owner occupied (block-group based)	.09	-.60
P_RENT	Percentage of total housing units that are occupied by renters (block-group based)	-.09	.60
PHU_G50	Percentage of housing units built prior to 1949 (1939 or earlier to 1949) (block-group based)	.34	-.74
PHU_G60	Percentage of housing units built prior to 1939 (block-group based)	.49	-.80
PHEL	Percentage of occupied housing units using electricity as fuel (block-group based)	-.02	.62
PHOIL	Percentage of occupied housing units using oil as fuel (block-group based)	.47	-.82
PHWOOD	Percentage of occupied housing units using wood as fuel (block-group based)	.39	-.91

Appendix 1-4. Reach-scale habitat charactersitics for 30 study sites in the Milwaukee to Green Bay, Wis., study area.

[%, percent; m, meter; m/m, meter by meter; m/km^2, meter per square kilometer; N/m^2, newtons per square meter; mm, millimeter; m^2/km^2, square meter per square kilometer; m^3, cubic meter; m^3/s, cubic millimeter per second; (m^3/s)/km^2, (cubic millimeter per second) per square kilometer]

Characteristic abbreviation	Characteristic definition (units)
	Riparian vegetation
RipLU	Disturbed land cover in 30-m buffer (%, out of 22 transect endpoints)
OCanAngleAvg	Mean open-canopy angle (degrees)
	Channel geomorphology
WaterSurfGradPct	Reach water-surface gradient/slope (%)
BFWidthAvg	Mean bankfull channel width (m)
BFWidthNoPools	Mean bankfull channel width (excluding pools) (m)
BFWidthDA	Mean bankfull width divided by drainage area (excluding pools) (m/km^2)
BFDepthAvg	Mean bankfull depth (m)
BFDepthNoPools	Mean bankfull depth (excluding pools) (m)
BFShear	Mean bankfull shear stress (N/m^2)
BFDepthDA	Bankfull depth divided by drainage area (excluding pools) (m/km^2)
BFWidthDepthAvg	Mean bankfull channel width-depth ratio (with pools)
BFWidthDepthNoPools	Mean bankfull channel width-depth ratio (excluding pools)
BFArea	Mean bankfull channel cross-sectional area (m^2)
BFAreaNoPools	Mean bankfull channel cross-sectional area (excluding pools) (m^2)
BFAreaDA	Mean bankfull channel cross-sectional area divided by drainage area (m^2/km^2)
BFAreaNoPoolsDA	Mean bankfull channel cross-sectional area divided by drainage area (excluding pools) (m^2/km^2)
BFD_{50}crit	Critical particle size (mm) for incipient motion (hydraulic radius (m) × slope (ratio) × 13.7 × 1,000 mm/1-m)
GCUTypeRiffPct	Relative proportion of the total length of all geomorphic channel units that are comprised of riffles (%)
GCUTypePoolPct	Relative proportion of the total length of all geomorphic channel units that are comprised of pools (%)
GCUTypeRunPct	Relative proportion of the total length of all geomorphic channel units that are comprised of runs (%)
GCUTypePoolRiff	Ratio of the area of pool geomorphic units to the area of riffle geomorphic channel units
GCUTypeRunRiff	Ratio of the area of run geomorphic units to the area of riffle geomorphic channel units
DepthAvg	Mean wetted channel depth (m)
DepthMax	Maximum wetted channel depth (m)
DepthCV	Coeffiecient of variation of wetted channel depth (m)
RchVol	Reach wetted channel volume = reach length multiplied by mean channel width multiplied by mean depth (m^3)
HydRadAvg	Mean wetted-channel hydraulic radius (m)
WidthDepthAvg	Mean wetted-channel width-depth ratio
WetXAreaAvg	Mean cross-sectional area of wetted channel (m^2)
ChStab	Channel stability = ratio of mean bankfull to wetted cross-sectional areas
ChShpCv	Coefficient of variation of wetted channel shape index
Froude	Froude number = mean flow velocity divided by (acceleration due to gravity multiplied by mean depth of water)$^{1/2}$ (dimensionless)

Appendix 1-4. Reach-scale habitat charactersitics for 30 sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[%, percent; m, meter; m/m, meter by meter; m/km^2, meter per square kilometer; N/m^2, newtons per square meter; mm, millimeter; m^2/km^2, square meter per square kilometer; m^3, cubic meter; m^3/s, cubic millimeter per second; (m^3/s)/km^2, (cubic millimeter per second) per square kilometer]

Characteristic abbreviation	Characteristic definition (units)
	Flow characteristics
VelocAvg	Mean velocity at the time of habitat sampling (m/s)
DischM3Sec	Instantaneous discharge at time of habitat sampling (m^3/s)
DischargeDA	Discharge at the time of habitat sampling divided by drainage area ((m^3/s)/km^2)
	Streambed substrate
BedSubMedian	Median dominant streambed substrate, calculated as D_{50} (mm)
FinesPct	Occurrence of transect points where the dominant substrate consists of particles that are less than 2 mm (%)
DomSub3Pct	Occurrence of transect points where the dominant substrate consists of sand (>0.062–2 mm) (%)
SiltCovPct	Occurrence of transect points where a silt layer was observed on streambed (%)
BedSubIndex[1]	Streambed Substrate Index—square-root differences of relative particle size categories
BedSubStab[2]	Streambed Substrate Stability Index—competence, incipient motion, based on Shield's criteria. D_{50}/D_{50} critical. D_{50} critical is based on bankfull hydraulic radius and slope
EmbedPctAvg	Mean embeddedness (%)
	Bank characteristics
BankErosPct	Occurrence of banks with erosion (presence/absence) (%)
BankVegCovAvg	Mean bank vegetative cover (%)
BankSubAvg	Mean bank substrate type[3] (category)
ErosionLengthAvg	Mean bank erosion length, average (m)

[1] Terry Short, U.S, Geological Survey, written commun., 2003.

[2] Kaufmann and others, 1999.

[3] Bank substrate types from Fitzpatrick and others (1998):

Description	Category number
Smooth bedrock/concrete/hardpan	1
Silt, clay, marl, muck, organic detritus	2
Sand (>0.063–2 mm)	3
Fine/medium gravel (>2–16 mm)	4
Coarse gravel (>16–32 mm)	5
Very coarse gravel (>32–64 mm)	6
Small cobble (>64–128 mm)	7
Large cobble (>128–256 mm)	8
Small boulder (>256–512 mm)	9
Large boulder, irregular bedrock, irregular hardpan, irregular artificial surface (>512 mm)	10

Appendix 1-5. Hydrologic-condition metrics used in the Milwaukee to Green Bay, Wis., study area.

[POR, period of record; m^2, square meter, >, greater than; ≥, greater than or equal to; <, less than; m^2/d; square meter per day; hr, hour; $(m^3/s)/km^2$, cubic meters per second per square kilometer. Suffixes "_pre" and "_post" were added to abbreviations to denote metrics that were calculated for the pre-ice period (Oct. 1–Dec. 8, 2003) and post-ice period (Mar. 16–Oct. 30, 2004), respectively.]

Metric abbreviation	Definition
cv	Coefficient of variation of cross-sectional area over all hours in POR
skew	Skew of cross-sectional area over all hours in POR
cv_log	Coefficient of variation of hourly cross-sectional-area values, where cross-sectional-area values are equal to log of 1 plus cross-sectional area
coeff_disp	75th-percentile cross-sectional area minus 25th-percentile cross-sectional area, divided by median cross-sectional area (dimensionless)
mean	Mean cross-sectional-area value over POR (m^2)
median	Median (50th-percentile) cross-sectional-area value over POR (m^2)
pct_99n	99th-percentile cross-sectional-area value over POR, divided by median cross-sectional-area value over POR (dimensionless)
pct_95n	95th-percentile cross-sectional-area value over POR, divided by median cross-sectional-area value over POR (dimensionless)
pct_90n	90th-percentile cross-sectional-area value over POR, divided by median cross-sectional-area value over POR (dimensionless)
pct_75n	75th-percentile cross-sectional-area value over POR, divided by median cross-sectional-area value over POR (dimensionless)
pct_25n	25th-percentile cross-sectional-area value over POR, divided by median cross-sectional-area value over POR (dimensionless)
pct_10n	10th-percentile cross-sectional-area value over POR, divided by median cross-sectional-area value over POR (dimensionless)
pct_5n	5th-percentile cross-sectional-area value over POR, divided by median cross-sectional-area value over POR (dimensionless)
pct_99a	99th-percentile cross-sectional-area value over POR (m^2)
pct_95a	95th-percentile cross-sectional-area value over POR (m^2)
pct_90a	90th-percentile cross-sectional-area value over POR (m^2)
pct_75a	75th-percentile cross-sectional-area value over POR (m^2)
pct_25a	25th-percentile cross-sectional-area value over POR (m^2)
pct_10a	10th-percentile cross-sectional-area value over POR (m^2)
pct_5a	5th-percentile cross-sectional-area value over POR (m^2)
day_pctchange	Sum of the absolute value of the relative change in daily mean cross-sectional area, divided by the daily mean cross-sectional area (dimensionless)
rb_flash	Version of Richards-Baker flashiness index (Baker and others, 2004), calculated as the sum of the absolute value of the relative change in daily mean cross-sectional area, divided by the sum of the daily mean cross-sectional area for the POR (dimensionless)
cumm_change	Sum of the absolute value of the total rise and fall in cross-sectional area over POR (m^2)
cumm_median	Sum of the absolute value of the total rise and fall in cross-sectional area over POR, divided by median cross-sectional area over POR (dimensionless)
med_torise	The median value of all rises over the POR. This is normalizing metric for "period" metrics below
med_tofall	The median value of all falls over the POR. This is normalizing metric for "period" metrics below
max_torise	The maximum change in cross-sectional area during one rise period
max_tofall	The maximum change in cross-sectional area during one falling period

Appendix 1-5. Hydrologic-condition characteristics used in the Milwaukee to Green Bay, Wis., study area—Continued.

[POR, period of record; m^2, square meter, >, greater than; ≥, greater than or equal to; <, less than; m^2/d; square meter per day; hr, hour; $(m^3/s)/km^2$, cubic meters per second per square kilometer. Suffixes "_pre" and "_post" were added to abbreviations to denote metrics that were calculated for the pre-ice period (Oct. 1–Dec. 8, 2003) and post-ice period (Mar. 16–Oct. 30, 2004), respectively.]

Metric abbreviation	Definition
max_durise	Maximum duration of consecutive periods of rising values over POR
max_durfall	Maximim duration of consecutive periods of falling values over POR
med_durise	Median duration of consecutive periods of rising values over POR
med_durfall	Median duration of consecutive periods of falling values over POR
periodr1	Frequency of rising cross-sectional-area events, where hourly cross-sectional-area change is ≥1 multiplied by the median rise over POR (number of hourly time periods)
periodr3	Frequency of rising cross-sectional-area events, where hourly cross-sectional-area change is ≥3 multiplied by the median rise over POR (number of hourly time periods)
periodr5	Frequency of rising cross-sectional-area events, where hourly cross-sectional-area change is ≥5 times the median rise over POR (number of hourly time periods)
periodr7	Frequency of rising cross-sectional-area events, where hourly cross-sectional-area change is ≥7 multiplied by the median rise over POR (number of hourly time periods)
periodr9	Frequency of rising cross-sectional-area events, where hourly cross-sectional-area change is ≥9 multiplied by the median rise over POR (number of hourly time periods)
periodf1	Frequency of falling cross-sectional-area events, where hourly cross-sectional-area change is ≥1 multiplied by the median fall over POR (number of hourly time periods)
periodf3	Frequency of falling cross-sectional-area events, where hourly cross-sectional-area change is ≥3 multiplied by the median fall over POR (number of hourly time periods)
periodf5	Frequency of falling cross-sectional-area events, where hourly cross-sectional-area change is ≥5 multiplied by the median fall over POR (number of hourly time periods)
periodf7	Frequency of falling cross-sectional-area events, where hourly cross-sectional-area change is ≥7 multiplied by the median fall over POR (number of hourly time periods)
periodf9	Frequency of falling cross-sectional-area events, where hourly cross-sectional-area change is ≥9 multiplied by the median fall over POR (number of hourly time periods)
MXH_75	Maximum duration of high cross-sectional-area pulses over POR (hr); high cross-sectional area >75th percentile
MXH_90	Maximum duration of high cross-sectional-area pulses over POR (hr); high cross-sectional area >90th percentile
MXH_95	Maximum duration of high cross-sectional-area pulses over POR (hr); high cross-sectional area >95th percentile
MDH_75	Median duration of high cross-sectional-area pulses over POR (hr); high cross-sectional area >75th percentile
MDH_90	Median duration of high cross-sectional-area pulses over POR (hr); high cross-sectional area >90th percentile
MDH_95	Median duration of high cross-sectional-area pulses over POR (hr); high cross-sectional area >95th percentile
MXL_25	Maximum duration of low cross-sectional-area pulses over POR (hr); low cross-sectional area <25th percentile
MXL_10	Maximum duration of low cross-sectional-area pulses over POR (hr); low cross-sectional area <10th percentile
MXL_5	Maximum duration of low cross-sectional-area pulses over POR (hr); low cross-sectional area <5th percentile
MDL_25	Median duration of low cross-sectional-area pulses over POR (hr); low cross-sectional area <25th percentile
MDL_10	Median duration of low cross-sectional-area pulses over POR (hr); low cross-sectional area <10th percentile
MDL_5	Median duration of low cross-sectional-area pulses over POR (hr); low cross-sectional area <5th percentile
Q_bnkfl	Flow corresponding to bankful stage as determined during habitat survey; model derived
Qmax_inst	Maximum instantaneous discharge
Q_max	Highest daily mean discharge
Q_ave	Annual mean dicharge

Appendix 1-5. Hydrologic-condition characteristics used in the Milwaukee to Green Bay, Wis., study—Continued.

[POR, period of record; m^2, square meter, >, greater than; ≥, greater than or equal to; <, less than; m^2/d; square meter per day; hr, hour; $(m^3/s)/km^2$, cubic meters per second per square kilometer. Suffixes "_pre" and "_post" were added to abbreviations to denote metrics that were calculated for the pre-ice period (Oct. 1–Dec. 8, 2003) and post-ice period (Mar. 16–Oct. 30, 2004), respectively.]

Metric abbreviation	Definition
Q_10	Discharge exceeded 10 percent of the time
Q_50	Discharge exceeded 50 percent of the time
Q_90	Discharge exceeded 90 percent of the time
Q_7min	Lowest mean discharge for 7 consecutive days
Q_min	Lowest daily mean
Q_bnkflDA	Flow corresponding to bankfull stage as determined during habitat surve, normalized by drainage area, $((m^3/s)/km^2)$
Qmax_instDA	Maximum instaneous discharge, normalized by drainage area, $((m^3/s)/km^2)$
Q_maxDA	Highest daily mean discharge, normalized by drainage area, $((m^3/s)/km^2)$
Q_aveDA	Annual mean dicharge, normalized by drainage area, $((m^3/s)/km^2)$
Q_10DA	Discharge exceeded 10 percent of the time, normalized by drainage area, $((m^3/s)/km^2)$
Q_50DA	Discharge exceeded 50 percent of the time, normalized by drainage area, $((m^3/s)/km^2)$
Q_90DA	Discharge exceeded 90 percent of the time, normalized by drainage area, $((m^3/s)/km^2)$
Q_7minDA	Lowest mean discharge for 7 consecutive days, normalized by drainage area, $((m^3/s)/km^2)$
Q_minDA	Lowest daily mean, normalized by drainage area, $((m^3/s)/km^2)$

Appendix 1-6. Water-chemistry characteristics used in the Milwaukee to Green Bay, Wis., study area.

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second; --, not applicable; °C; degrees Celsius; col/100 mL, colonies per 100 milliliters; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; $CaCO_3$, calcium carbonate; %, percent; mm, millimeter; N, Nitrogen; µg/L, micrograms per liter; P, phosphorus]

Characteristic abbreviation	Definition	USGS parameter code	Chemical class	Use	Parent compound
INSTDIS	Discharge, instantaneous (ft^3/s)	P00061	--	--	--
WTEMP	Temperature, water (°C)	P00010	--	--	--
DISSOX	Dissolved oxygen, water, unfiltered (mg/L)	P00300	--	--	--
PH	pH, water, unfiltered, field (standard units)	P00400	--	--	--
SPCOND	Specific conductance, water, unfiltered (µS/cm)	P00095	--	--	--
ALK	Alkalinity, dissolved, field, incremental titration (mg/L as $CaCO_3$)	P39086	--	--	--
CARB	Carbonate, dissolved, field, incremental titration (mg/L)	P00452	--	--	--
BICARB	Bicarbonate, dissolved, field, incremental titration (mg/L)	P00453	--	--	--
PCTFINES	Suspended sediment, sieve diameter (% smaller than 0.063 mm)	P70331	--	--	--
SUSSED	Suspended sediment concentration (mg/L)	P80154	--	--	--
CHLOR	Chloride, water, filtered (mg/L)	P00940	--	--	--
SULFA	Sulfate, water, filtered (mg/L)	P00945	--	--	--
TKNITR	Ammonia plus organic nitrogen, water, unfiltered (mg/L as N)	P00625	--	--	--
AMMON	Ammonia, water, filtered (mg/L as N)	P00608	--	--	--
NITRATE	Nitrate, water, filtered (mg/L as N)	P00618	--	--	--
NOX	Nitrite plus nitrate, water, filtered (mg/L as N)	P00631	--	--	--
NITRITE	Nitrite, water, filtered (mg/L as N)	P00613	--	--	--
ORTHOP	Orthophosphate, water, filtered (mg/L as P)	P00671	--	--	--
PARTN	Particulate nitrogen, suspended in water (mg/L as N)	P49570	--	--	--
TOTALP	Phosphorus, water, unfiltered (mg/L as P)	P00665	--	--	--
TOTALN	Total nitrogen, water, unfiltered (mg/L as N)	P00600	--	--	--
TPARTC	Carbon (inorganic plus organic), suspended sediment, total (mg/L)	P00694	--	--	--
PINORGC	Inorganic carbon, suspended sediment, total (mg/L)	P00688	--	--	--
PORGC	Organic carbon, suspended sediment, total (mg/L)	P00689	--	--	--
DISORGC	Organic carbon, water, filtered (mg/L)	P00681	--	--	--
NAPHT	1-Naphthol, water, filtered, recoverable (µg/L)	P49295	Phenol	Degradate	Carbaryl, napropamide

Appendix 1-6. Water-chemistry characteristics used in the Milwaukee to Green Bay, Wis., study area—Continued.

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second; --, not applicable; ºC; degrees Celsius; col/100 mL, colonies per 100 milliliters; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; $CaCO_3$, calcium carbonate; %, percent; mm, millimeter; N, Nitrogen; µg/L, micrograms per liter; P, phosphorus]

Characteristic abbreviation	Definition	USGS parameter code	Chemical class	Use	Parent compound
DIETH	2,6-Diethylaniline, water, filtered, recoverable (µg/L)	P82660	Degradate	Degradate	Alachlor
PROPA	2-[(2-Ethyl-6-methylphenyl)-amino]-1-propanol, water, filtered, recoverable (µg/L)	P61615	Aniline	Degradate	Metolachlor
CHLDI	2-Chloro-2’,6’-diethylacetanilide, water, filtered, recoverable (µg/L)	P61618	Acetanilide	Degradate	Alachlor
CHLIS	2-Chloro-4-isopropylamino-6-amino-s-triazine, water, filtered, recoverable (µg/L)	P04040	Triazine	Degradate	Atrazine
ETHYL	2-Ethyl-6-methylaniline, water, filtered, recoverable (µg/L)	P61620	Aniline	Degradate	Metolachlor
DICHL	3,4-Dichloroaniline, water, filtered, recoverable (µg/L)	P61625	Aniline	Degradate	Diuron/propanil/ linuron/neburon
CHLME	4-Chloro-2-methylphenol, water, filtered, recoverable (µg/L)	P61633	Phenol	Degradate	Mcpa/mcpb
ACETO	Acetochlor, water, filtered, recoverable (µg/L)	P49260	Acetanilide	Herbicide	--
ALACH	Alachlor, water, filtered, recoverable (µg/L)	P46342	Acetanilide	Herbicide	--
ATRAZ	Atrazine, water, filtered, recoverable (µg/L)	P39632	Triazine	Herbicide	--
AZMEO	Azinphos-methyl oxygen analog, water, filtered, recoverable (µg/L)	P61635	Organophosphate	Degradate	Azinphos-methyl
AZMET	Azinphos-methyl, water, filtered , recoverable (µg/L)	P82686	Organophosphate	Insecticide	--
BENFL	Benfluralin, water, filtered , recoverable (µg/L)	P82673	Dinitroaniline	Herbicide	--
CARBA	Carbaryl, water, filtered , recoverable (µg/L)	P82680	Carbamate	Insecticide	--
CHLOX	Chlorpyrifos oxygen analog, water, filtered, recoverable (µg/L)	P61636	Organophosphate	Degradate	Chlorpyrifos
CHLOP	Chlorpyrifos, water, filtered, recoverable (µg/L)	P38933	Organophosphate	Insecticide	--
PERME	cis-Permethrin, water, filtered , recoverable (µg/L)	P82687	Pyrethroid	Insecticide	--
CYFLU	Cyfluthrin, water, filtered, recoverable (µg/L)	P61585	Pyrethroid	Insecticide	--
CYPER	Cypermethrin, water, filtered, recoverable (µg/L)	P61586	Pyrethroid	Insecticide	--
DCPA	DCPA, water, filtered , recoverable (µg/L)	P82682	Chlorobenzoic acid ester	Herbicide	--
DESFI	Desulfinyl fipronil, water, filtered, recoverable (µg/L)	P62170	Phenyl pyrazole	Degradate	Fipronil
DIAZO	Diazinon oxygen analog, water, filtered, recoverable (µg/L)	P61638	Organophosphate	Degradate	Diazinon
DIAZI	Diazinon, water, filtered, recoverable (µg/L)	P39572	Organophosphate	Insecticide	--
DICRO	Dicrotophos, water, filtered, recoverable (µg/L)	P38454	Organophosphate	Insecticide	--

Appendix 1-6. Water-chemistry characteristics used in the Milwaukee to Green Bay, Wis., study area—Continued.

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second; --, not applicable; ºC; degrees Celsius; col/100 mL, colonies per 100 milliliters; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; $CaCO_3$, calcium carbonate; %, percent; mm, millimeter; N, Nitrogen; µg/L, micrograms per liter; P, phosphorus]

Characteristic abbreviation	Definition	USGS parameter code	Chemical class	Use	Parent compound
DIELD	Dieldrin, water, filtered, recoverable (µg/L)	P39381	Organochlorine	Insecticide/ degradate	Aldrin
DIMET	Dimethoate, water, filtered , recoverable (µg/L)	P82662	Organophosphate	Insecticide	--
ETHIM	Ethion monoxon, water, filtered, recoverable (µg/L)	P61644	Organophosphate	Degradate	Ethion
ETHIO	Ethion, water, filtered, recoverable (µg/L)	P82346	Organophosphate	Insecticide	--
FENSN	Fenamiphos sulfone, water, filtered, recoverable (µg/L)	P61645	Organophosphate	Degradate	Fenamiphos
FENSX	Fenamiphos sulfoxide, water, filtered, recoverable (µg/L)	P61646	Organophosphate	Degradate	Fenamiphos
FENAM	Fenamiphos, water, filtered, recoverable (µg/L)	P61591	Organophosphate	Nematocide	--
DESAM	Desulfinylfipronil amide, water, filtered, recoverable (µg/L)	P62169	Phenyl pyrazole	Degradate	Fipronil
FIPSD	Fipronil sulfide, water, filtered, recoverable (µg/L)	P62167	Phenyl pyrazole	Degradate	Fipronil
FIPSN	Fipronil sulfone, water, filtered, recoverable (µg/L)	P62168	Phenyl pyrazole	Degradate	Fipronil
FIPRO	Fipronil, water, filtered, recoverable (µg/L)	P62166	Phenyl pyrazole	Insecticide	--
FONOX	Fonofos oxygen analog, water, filtered, recoverable (µg/L)	P61649	Organophosphate	Degradate	Fonofos
FONOF	Fonofos, water, filtered, recoverable (µg/L)	P04095	Organophosphate	Insecticide	--
HEXAZ	Hexazinone, water, filtered, recoverable (µg/L)	P04025	Triazine	Herbicide	--
IPROD	Iprodione, water, filtered, recoverable (µg/L)	P61593	Dicarboximide	Fungicide	--
ISOFE	Isofenphos, water, filtered, recoverable (µg/L)	P61594	Organophosphate	Insecticide	--
MALAO	Malaoxon, water, filtered, recoverable (µg/L)	P61652	Organophosphate	Degradate	Malathion
MALAT	Malathion, water, filtered, recoverable (µg/L)	P39532	Organophosphate	Insecticide	--
METAL	Metalaxyl, water, filtered, recoverable (µg/L)	P61596	Amino acid derivative	Fungicide	--
METHI	Methidathion, water, filtered, recoverable (µg/L)	P61598	Organophosphate	Insecticide	--
METPX	Methyl paraoxon, water, filtered, recoverable (µg/L)	P61664	Organophosphate	Degradate	Methyl parathion
METPT	Methyl parathion, water, filtered, recoverable (µg/L)	P82667	Organophosphate	Insecticide	--
METOL	Metolachlor, water, filtered, recoverable (µg/L)	P39415	Acetanilide	Herbicide	--
METRI	Metribuzin, water, filtered, recoverable (µg/L)	P82630	Triazine	Herbicide	--
MYCLO	Myclobutanil, water, filtered, recoverable (µg/L)	P61599	Triazole	Fungicide	--
PENDI	Pendimethalin, water, filtered, recoverable (µg/L)	P82683	Dinitroaniline	Herbicide	--

Appendix 1-6. Water-chemistry characteristics used in the Milwaukee to Green Bay, Wis., study area—Continued.

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second; --, not applicable; ºC; degrees Celsius; col/100 mL, colonies per 100 milliliters; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; $CaCO_3$, calcium carbonate; %, percent; mm, millimeter; N, Nitrogen; µg/L, micrograms per liter; P, phosphorus]

Characteristic abbreviation	Definition	USGS parameter code	Chemical class	Use	Parent compound
PHOOX	Phorate oxygen analog, water, filtered, recoverable (µg/L)	P61666	Organophosphate	Degradate	Phorate
PHORA	Phorate, water, filtered, recoverable (µg/L)	P82664	Organophosphate	Insecticide	--
PHOSO	Phosmet oxygen analog, water, filtered, recoverable (µg/L)	P61668	Organophosphate	Degradate	Phosmet
PHOSM	Phosmet, water, filtered, recoverable (µg/L)	P61601	Organophosphate	Insecticide	--
PROME	Prometon, water, filtered, recoverable (µg/L)	P04037	Triazine	Herbicide	--
PROMY	Prometryn, water, filtered, recoverable (µg/L)	P04036	Triazine	Herbicide	--
PRONA	Pronamide, water, filtered, recoverable (µg/L)	P82676	Amide	Herbicide	--
SIMAZ	Simazine, water, . ltered, recoverable (µg/L)	P04035	Triazine	Herbicide	--
TEBUT	Tebuthiuron, water, filtered, recoverable (µg/L)	P82670	Urea	Herbicide	--
TERBO	Terbufos oxygen analog sulfone, water, filtered, recoverable (µg/L)	P61674	Organophosphate	Degradate	Terbufos
TERBF	Terbufos, water, filtered, recoverable (µg/L)	P82675	Organophosphate	Insecticide	--
TERBU	Terbuthylazine, water, filtered, recoverable (µg/L)	P04022	Triazine	Herbicide	--
TRIFL	Trifluralin, water, filtered, recoverable (µg/L)	P82661	Dinitroaniline	Herbicide	--
DICHL	Dichlorvos, water, filtered, recoverable (µg/L)	P38775	Organophosphate	Insecticide, fumigant, degradate	Naled
TPCONC	Total pesticide concentration (µg/L)	--	--	--	--
THCONC	Total herbicide concentration (µg/L)	--	--	--	--
TICONC	Total insecticide concentration (µg/L)	--	--	--	--
NUMP	Number of pesticides detected	--	--	--	--
NUMH	Number of herbicides detected	--	--	--	--
NUMI	Number of insecticides detected	--	--	--	--
PTI_CLAD	Pesticide toxicity index for cladocerans	--	--	--	--
PTI_INV	Pesticide toxicity index for benthic invertebrates	--	--	--	--
PTI_FISH	Pesticide toxicity index for freshwater fish	--	--	--	--

Appendix 1-7. Semipermeable membrane device (SPMD) chemical characteristics used in the Milwaukee to Green Bay, Wis., study area.

[--, not applicable; EI, electron impact ionization; ECNI, electron capture negative ionization]

Characteristic abbreviation	Definition	Ionization technique
TEQ	SPMD toxicity, CYP1A1 production (toxic equivalents)	--
UPAH	SPMD toxicity, ultraviolet fluourescence (micrograms pyrene)	--
EC50	SPMD toxicity, Microtox assay (EC50)	--
S_14DICH	1,4-Dichlorobenzene	EI
S_1MENAP	1-Methylnapthalene	EI
S_DMENAP	2,6-Dimethylnapthalene	EI
S_2MBENZ	2-Methyl benzothiophene	EI
S_2MENAP	2-Methylnapthalene	EI
S_34DICH	3,4-Dichlorophenyl isocyanate	EI
S_CUMYL	4-Cumylphenol	EI
S_OCTYL	4-Octylphenol	EI
S_TOCTYL	4-tert-Octylphenol	EI
S_MHBENZ	5-Methyl-1H-benzotriazone	EI
S_ACET	Acetophenone	EI
S_AHTN	Acetyl hexamethyl tetrahydronaphthalene (AHTN)	EI
S_ALDRIN	Aldrin	ECNI
S_AHCH	Alpha-HCH	ECNI
S_ANTHRC	Anthracene	EI
S_ANTHRQ	Anthraquinone	EI
S_BDE100	2,2’,4,4’,6-Pentabromodiphenyl ether (BDE 100)	ECNI
S_BDE153	2,2’,4,4’,5,5’-Hexabromodiphenyl ether (BDE 153)	ECNI
S_BDE154	2,2’,4,4’,5,6’-Hexabromodiphenyl ether (BDE 154)	ECNI
S_BDE47	2,2´,4,4´-Tetrabromodiphenyl ether (BDE 47)	ECNI
S_BDE99	2,2’,4,4’,5-Pentabromodipenyl ether (BDE 99)	ECNI
S_BENFL	Benfluralin	ECNI
S_BAPYR	Benzo-(a)-pyrene	EI
S_BENZO	Benzophenone	EI
S_BCOPR	Beta-coprostanol	EI
S_BHCH	Beta-HCH	ECNI
S_BSITO	Beta-sitosterol	EI
S_BHA	3-tert-Butyl-4-hydroxy anisole (BHA)	EI
S_BISPH	Bisphenol A	EI
S_BROMA	Bromacil	EI
S_BROMO	Bromoform	EI
S_CAFF	Caffeine	EI
S_CAMPH	Camphor	EI
S_CARBA	Carbaryl	EI
S_CARBAZ	Carbazole	EI
S_CHLOP	Chlorpyrifos	ECNI
S_CHOL	Cholesterol	EI
S_CCHLOR	cis-Chlordane	ECNI
S_CNONAC	cis-Nonachlor	ECNI

Appendix 1-7. Semipermeable membrane device (SPMD) chemical characteristics used in the Milwaukee to Green Bay, Wis., study area—Continued.

[--, not applicable; EI, electron impact ionization; ECNI, electron capture negative ionization]

Characteristic abbreviation	Definition	Ionization technique
S_COTIN	Cotinine	EI
S_CUMEN	Cumene	EI
S_DCPA	Dacthal (DCPA)	ECNI
S_DHCH	Delta-HCH	ECNI
S_DIAZI	Diazinon	EI
S_DIELD	Dieldrin	ECNI
S_DPHTA	Diethyl phtalate	EI
S_DHPHTA	Diethylhexyl phthalate	EI
S_DEET	N,N-Diethyl-meta-toluamide (DEET)	EI
S_DPYRAZ	Diphenyl pyrazole	EI
S_LIMO	d-Limonene	EI
S_ENDOI	Endosulfan I	ECNI
S_ENDOII	Endosulfan II	ECNI
S_ENDOSF	Endosulfan sulfate	ECNI
S_ENDRN	Endrin	ECNI
S_ENDRNA	Endrin aldehyde	ECNI
S_ENDRNK	Endrin ketone	ECNI
S_ETHPH	Ethanol, 2-butoxy-, phosphosphate	EI
S_ECITR	Ethyl citrate	EI
S_FIPRO	Fipronil	ECNI
S_FLUOR	Fluoranthene	EI
S_GHCH	Gamma-HCH	ECNI
S_HCB	Hexachlorobenzene (HCB)	ECNI
S_HEPTEP	Heptachlor epoxide	ECNI
S_HHCB	Hexahydrohexamethylcyclopentabenzopyran (HHCB)	EI
S_INDOLE	Indole	EI
S_ISOBO	Isoborneol	EI
S_ISOPHO	Isophorone	EI
S_ISOQU	Isoquinoline	EI
S_MENTH	Menthol	EI
S_METAL	Metalaxyl	EI
S_MSALI	Methyl saliciylate	EI
S_METOL	Metolachlor	EI
S_MIREX	Mirex	ECNI
S_NAPTH	Napthalene	EI
S_NPEO1	Nonylphenol monoethoxylate (NPEO1)	EI
S_NPEO2	Nonylphenol diethoxylate (NPEO2)	EI
S_OPDDD	o,p’-DDD	ECNI
S_OPDDE	o,p’-DDE	ECNI
S_OPDDT	o,p’-DDT	ECNI
S_OCTSTY	Octachlorostyrene	ECNI
S_OPEO1	Octylphenol monoethoxylate (OPEO1)	EI

Appendix 1-7. Semipermeable membrane device (SPMD) chemical characteristics used in the Milwaukee to Green Bay, Wis., study area—Continued.

[--, not applicable; EI, electron impact ionization; ECNI, electron capture negative ionization]

Characteristic abbreviation	Definition	Ionization technique
S_OPEO2	Octylphenol diethoxylate (OPEO2)	EI
S_OXYCHL	Oxychlordane	ECNI
S_PPDDD	p,p’-DDD	ECNI
S_PPDDE	p,p’-DDE	ECNI
S_PPDDT	p,p’-DDT	ECNI
S_PCRES	p-Cresol	EI
S_PNONYL	p-Nonylphenol, total	EI
S_PCA	Pentachloroanisole (PCA)	ECNI
S_PCB70	2,3’4’,5-Tetrachlorobiphenyl (PCB 70)	ECNI
S_PCB101	2,2’,4,5,5’-Pentachlorobiphenyl (PCB 101)	ECNI
S_PCB110	2,3,3’,4’,6-Pentachlorobiphenyl (PCB 110)	ECNI
S_PCB118	2,3’,4,4’,5-Pentachlorobiphenyl (PCB 118)	ECNI
S_PCB138	2,2’,3,4,4’,4’,5-Hexachlorobiphenyl (PCB 138)	ECNI
S_PCB146	2,2’,3,4’,5,5’-Hexachlorobiphenyl (PCB 146)	ECNI
S_PCB149	2,2’,3,4’,5’,6-Hexachlorobiphenyl (PCB 149)	ECNI
S_PCB151	2,2’,3,5,5’,6-Hexachlorobiphenyl (PCB 151)	ECNI
S_PCB170	2,2’,3,3’,4,4’,5-Heptachlorobiphenyl (PCB 170)	ECNI
S_PCB174	2,2’,3,3’,4,5,6’-Heptachlororbiphenyl (PCB 174)	ECNI
S_PCB177	2,2’,3,3’,4,5’,6’-Heptachlorobiphenyl (PCB 177)	ECNI
S_PCB180	2,2’,3,4,4’,5,5’-Heptachlorobiphenyl (PCB 180)	ECNI
S_PCB183	2,2’,3,4,4’,5’,6- Heptachlorobiphenyl (PCB 183)	ECNI
S_PCB187	2,2’,3,4’,5,5’,6-Heptachlorobiphenyl (PCB 187)	ECNI
S_PCB194	2,2’,3,3’,4,4’,5,5’-Octachlorobiphenyl (PCB 194)	ECNI
S_PCB206	2,2’,3,3’,4,4’,5,5’,6-Nonachlorobiphenyl (PCB 206)	ECNI
S_PHENA	Phenanthrene	EI
S_PROME	Prometon	EI
S_PHENO	Phenol	EI
S_PYRE	Pyrene	EI
S_SKAT	3-Methyl-1(H)-indole (skatole)	EI
S_STIG	Stigmastanol	EI
S_TOXAPH	Toxaphene	ECNI
S_TCHLOR	Trans-chlordane	ECNI
S_TNONAC	Trans-nonachlor	ECNI
S_TCPHOS	Tris (2-chloroethyl) phosphate	EI
S_TDPHOS	Tri (dichloroisopropyl) phosphate	EI
S_TBPHOS	Tributylphosphate	EI
S_TRICL	Triclosan	EI
S_TRIFL	Trifluralin	ECNI
S_TPPHOS	Triphenyl phosphate	EI

Appendix 1-8. Algal metrics used in data analysis for the Milwaukee to Green Bay, Wis., study area. All metrics are defined in Porter (2008).

[DCA, detrended correspondance analysis; DOS, dissolved oxygen saturation; %, percent; BOD5, Biochemical oxygen demand (5-day test); %, percent; mg/L, milligrams per liter; OBN, organically bound nitrogen; cm^2, square centimeter; ppt, parts per thousand]

Metric abbreviation	Definition
aDCA Axis 1	Algae DCA axis 1 score
aDCA Axis 2	Algae DCA axis 1 score
aDCA Axis 3	Algae DCA axis 1 score
aDCA Axis 4	Algae DCA axis 1 score
BioDtms	Sum of biovolume of all diatoms in sample
NumTax_all	Sample taxa richness
NumTax_dtm	Sample diatom taxa richness
CellDens_tot	Sample total cell density, in cells per square centimeter
CP	Ratio of centric to pennate diatoms
SiltIdx	Percent relative abundance of diatoms in genera containing mostly motile species
	Saprobity
SP_OL	Saprobien index: oligosaprobous (DOS: greater than 85%; BOD5: less than 2 mg/L)
SP_BM	Saprobien index: β-mesosaprobous (DOS: 70-80%; BOD5: 2–4 mg/L)
SP_AM	Saprobien index: α-mesosaprobous (DOS: 25-70%; BOD5: 4–13 mg/L)
SP_PS	Saprobien index: polysaprobous (DOS: less than 10%; BOD5: greater than 22 mg/L)
SP_AP	Saprobien index: α-meso-/polysaprobous (DOS: 10-25%; BOD5: 13-22 mg/L)
	Organic nitrogen uptake mechanism
ON_AL	Nitrogen autotroph (low inorganic N; intolerant to OBN; some taxa may be oligotraphentic or mesotraphentic)
ON_AH	Nitrogen autotroph (high inorganic N; tolerant to OBN; some taxa may be eutraphentic)
ON_HF	Nitrogen heterotroph (facultative organic N; requiring periodic elevated concentrations of OBN)
ON_HO	Nitrogen heterotroph (obligate organic N; indicative of elevated concentrations of OBN)
ON_NH	Nitrogen heterotrophs (ON_HF + ON_HO; indicative of elevated concentrations of OBN)
NF_YS	Nitrogen fixer: capable of fixing atmospheric nitrogen
	Preferred trophic condition
TR_OL	Oligotrophic diatoms
TR_OM	Oligotrophic-mesotrophic diatoms
TR_MT	Mesotrophic diatoms
TR_ET	Eutrophic diatoms
TR_PT	Polytrophic diatoms
TR_EY	Eurytrophic diatoms
TR_E	All eutrophic diatoms (combination of mesotrophic-eutrophic, polytrophic, and eurytrophic diatoms)
TR_O	All oligotrophic diatoms (combination of oligotrophic and oligotrophic-mesotrophic diatoms)
EUTROPHIC	All eutrophic algae (combination of mesotrophic-eutrophic, polytrophic, and eurytrophic diatoms and soft algae)
	Pollution class
PC_MT	Bahls' pollution class: most tolerant (very tolerant to nutrient and organic enrichment)
PC_LT	Bahls' pollution class: less tolerant (somewhat tolerant to nutrient and organic enrichment)
PC_SN	Bahls' pollution class: sensitive (somewhat intolerant to nutrient and organic enrichment; not necessarily "oligotrophic")

Appendix 1-8. Algal metrics used in data analysis for the Milwaukee to Green Bay, Wis., study area. All metrics are defined in Porter (2008)—Continued

[DCA, detrended correspondance analysis; DOS, dissolved oxygen saturation; %, percent; BOD5, Biochemical oxygen demand (5-day test); %, percent; mg/L, milligrams per liter; OBN, organically bound nitrogen; cm^2, square centimeter; ppt, parts per thousand]

Metric abbreviation	Definition
	Pollution tolerance
PT_VT	Lange-Bertalot pollution tolerance: very tolerant (taxa preferring polysaprobic conditions: extremely degraded conditions: hypeutrophic)
PT_TA	Lange-Bertalot pollution tolerance designation: tolerant (taxa preferring alpha-meso/polysaprobic conditions: highly degraded conditions: eutrophic)
PT_TB	Lange-Bertalot pollution tolerance designation: tolerant (taxa preferring alpha-mesosaprobic conditions: degraded, organically-enriched conditions: eutrophic)
PT_LA	Lange-Bertalot pollution tolerance: less tolerant (taxa preferring beta-mesosaprobic conditions: somewhat degraded conditions; meso-eutrophic; mesotrophic)
PT_LB	Lange-Bertalot pollution tolerance designation: less tolerant (taxa preferring oligosaprobic conditions: low amounts of organic enrichment: mesotrophic; oligo-mesotrophic)
	Preferred salinity condition
SL_FR	Fresh water (less than 100 mg/L chloride; less than 0.2 ppt salinity)
SL_FB	Fresh-brackish water (less than 500 mg/L chloride; less than 0.9 ppt salinity)
SL_BF	Brackish-fresh water (500–1,000 mg/L chloride; 0.9–1.8 ppt salinity)
SL_BR	Brackish water (1000 - 5000 mg/L chloride; 1.8 - 9.0 ppt salinity)
SL_HB	Halobiontic water (SL_BF + SL_BR; greater than 500 mg/l chloride; greater than 0.9 ppt salinty)
	Preferred pH condition
PH_AB	Acidobiontic (pH optimum less than 5.5)
PH_AP	Acidophilic (pH optimum less than 7)
PH_CN	Circumneutral (pH near 7)
PH_LP	Alkaliphilous (pH near 7 or greater)
PH_LB	Alkalibiontic (pH optimum greater than 7)
PH_IF	Indifferent (no apparent pH optimum)
	Benthic-sestonic taxa
BS_BE	Taxa primarily or exclusively associated with benthic substrates
	Moisture Requirement
MS_OW	taxa common in stream channels, springs, seeps, and ditches
	Preferred oxygen saturation
OT_AH	Always high (conditions with nearly 100% DOS)
OT_FH	Fairly high (conditions with greater than 75% DOS)
OT_MD	Moderate (conditions with greater than 50% DOS)
OT_LW	Low (conditions with greater than 30% DOS)

Appendix 1-9. Benthic macroinvertebrate metrics used in data analysis for 30 study sites in the Milwaukee to Green Bay, Wis., study area.

[Detrended Correspondence Analysis (DCA) for richest-targeted-habitat, percent density, all species, all sites. Except for DCA metrics, all metric abbreviations are from Cuffney (2003).]

Metric abbreviation	Definition
	DCA metrics
iDCA Axis 1	Invertebrate DCA Axis 1 site scores
iDCA Axis 2	Invertebrate DCA Axis 2 site scores
iDCA Axis 3	Invertebrate DCA Axis 3 site scores
iDCA Axis 4	Invertebrate DCA Axis 4 site scores
	Tolerance metrics (Barbour and others, 1999)
RICHTOL	Average USEPA tolerance values for sample based on richness
ABUNDTOL	Abundance-weighted USEPA tolerance value for sample
	Individual abundance metrics
ABUND	Total number of individual invertebrates in sample
AMPHI	Abundance of Amphipoda
AMPHIp	Percentage of total abundance composed of Amphipoda
BIVALV	Abundance of Bivalvia
BIVALp	Percentage of total abundance composed of Bivalvia
CH	Abundance of midges
CHp	Percentage of total abundance composed of midges
COLEOP	Abundance of Coleoptera
COLEOPp	Percentage of total abundance composed of Coleoptera
CORBIC	Abundance of *Corbicula*
CORBICp	Percentage of total abundance composed of *Corbicula*
DIP	Abundance of Diptera
DIPp	Percentage of total abundance composed of Diptera
EPEM	Abundance of Ephemeroptera (mayflies)
EPEMp	Percentage of total abundance composed of Ephemeroptera (mayflies)
EPT	Abundance of EPT (Ephemeroptera, Plecoptera, and Trichoptera)
EPTp	Percentage of total abundance composed of EPT (Ephemeroptera, Plecoptera, and Trichoptera)
EPT_CHp	Ratio of EPT (Ephemeroptera, Plecoptera, Trichoptera) abundance to midge abundance
GASTRO	Abundance of Gastropoda
GASTROp	Percentage of total abundance composed of Gastropoda
ISOPOD	Abundance of Isopoda
ISOPp	Percentage of total abundance composed of Isopoda
MOLCRU	Abundance of Mollusca and Crustacea
MOLCRUp	Percentage of total abundance composed of Mollusca and Crustacea
NCHDIP	Abundance of non-midge Diptera
NCHDIPp	Percentage of total abundance composed of non-midge Diptera
NONINS	Abundance of non-insects
NONINSp	Percentage of total abundance composed of non-insects
ODIPNI	Abundance composed of non-midge Diptera and non-insects
ODIPNIp	Percentage of total abundance composed of non-midge Diptera and non-insects

Appendix 1-9. Benthic macro-invertebrate metrics used in data analysis for 30 study sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[Detrended Correspondence Analysis (DCA) for richest-targeted-habitat, percent density, all species, all sites. Except for DCA metrics, all metric abbreviations are from Cuffney (2003).]

Metric abbreviation	Definition
	Individual abundance metrics (continued)
ODONO	Abundance of Odonata
ODONOp	Percentage of total abundance composed of Odonata
OLIGO	Abundance composed of Oligochaeta
OLIGOp	Percentage of total abundance composed of Oligochaeta
ORTHO	Abundance of Orthocladinae midges
ORTHOp	Percentage of total abundance composed of Orthocladinae midges
ORTHO_CHp	Ratio of Orthocladinae midge abundance to midge abundance
PLECO	Abundance of Plecoptera (stoneflies)
PLECOp	Percentage of total abundance composed of Plecoptera (stoneflies)
PTERY	Abundance of *Pteronarcys* stoneflies
PTERYp	Percentage of total abundance composed of *Pteronarcys* stoneflies
TANY	Abundance of Tanytarsanii midges
TANYp	Percentage of total abundance composed of Tanytarsinii midges
TANY_CHp	Ratio of Tanytarsinii midge abundance to midge abundance
TRICH	Abundance of Trichoptera (caddisflies)
TRICHp	Percentage of total abundance composed of Trichoptera (caddisflies)
	Taxa-richness metrics
RICH	Richness of invertebrate taxa in sample (number of unique, non-ambiguous taxa)
AMPHIR	Richness composed of Amphipoda
AMPHIRp	Percentage of total richness composed of Amphipoda
BIVALRp	Percentage of total richness composed of Bivalvia
BIVALVR	Richness composed of Bivalvia
CHR	Richness composed of midges
CHRp	Percentage of total richness composed of midges
COLEOPR	Richness composed of Coleoptera
COLEOPRp	Percentage of total richness composed of Coleoptera
CORBICR	Richness composed of *Corbicula*
CORBICRp	Percentage of total richness composed of *Corbicula*
DIPR	Richness composed of Diptera
DIPRp	Percentage of total richness composed of Diptera
EPEMR	Richness composed of Ephemeroptera (mayflies)
EPEMRp	Percentage of total richness composed of Ephemeroptera (mayflies)
EPT_CHRp	Ratio of EPT (Ephemeroptera, Plecoptera, Trichoptera) percent richness to midge percent richness
EPTR	Richness composed of EPT (Ephemeroptera, Plecoptera, Trichoptera)
EPTRp	Percentage of total richness composed of EPT (Ephemeroptera, Plecoptera, Trichoptera)
GASTROR	Richness composed of Gastropoda
GASTRORp	Percentage of total richness composed of Gastropoda
ISOPODR	Richness composed of Isopoda
ISOPODRp	Percentage of total richness composed of Isopoda

Appendix 1-9. Benthic macro-invertebrate metrics used in data analysis for 30 study sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[Detrended Correspondence Analysis (DCA) for richest-targeted-habitat, percent density, all species, all sites. Except for DCA metrics, all metric abbreviations are from Cuffney (2003).]

Metric abbreviation	Definition
	Taxa-richness metrics (continued)
MOLCRUR	Richness composed of Mollusca and Crustacea
MOLCRURp	Percentage of total richness composed of Mollusca and Crustacea
NCHDIPR	Richness composed of non-midge Diptera
NCHDIPRp	Percentage of total richness composed of non-midge Diptera
NONINSR	Richness composed of non-insects
NONINSRp	Percentage of total richness composed on non-insects
ODIPNIR	Richness composed of non-midge Diptera and non-insects
ODIPNIRp	Percentage of total richness composed of non-midge Diptera and non-insects
ODONOR	Richness composed of Odonata
ODONORp	Percentage of total richness composed of Odonata
OLIGOR	Richness composed of Oligochaeta
OLIGORp	Percentage of total richness composed of Oligochaeta
ORTHO_CHRp	Ratio of Orthocladinae midge percent richness to midge percent richness
ORTHOR	Richness composed of Orthocladinae midges
ORTHORp	Percentage of total richness composed of orthocladinae midges
PLECOR	Richness composed of Plecoptera (stoneflies)
PLECORp	Percentage of total richness composed of stoneflies (Plecoptera)
PTERYR	Richness composed of *Pteronarcys* stoneflies
PTERYRp	Percentage of total richness composed of *Pteronarcys* stoneflies
TANY_CHRp	Ratio of Tanytarsanii percent richness to midge percent richness
TANYR	Richness composed of Tanytarsanii midges
TANYRp	Percentage of total richness composed of Tanytarsanii midges
TRICHR	Richness composed of Trichoptera (caddisflies)
TRICHRp	Percentage of total richness composed of caddisflies (Trichoptera)
	Functional group metrics
FC_Abund	Total abundance composed of filtering-collectors
pFC_Abund	Percentage of total abundance composed of filtering-collectors
FC_Rich	Richness composed of filtering-collectors
pFC_Rich	Percentage of total richness composed of filtering-collectors
GC_Abund	Total abundance composed of gatherer-collectors
pGC_Abund	Percentage of total abundance composed of gatherer-collectors
GC_Rich	Richness composed of gatherer-collectors
pGC_Rich	Percentage of total richness composed of gatherer-collectors
OM_Abund	Total abundance composed of omnivores
pOM_Abund	Percentage of total abundance composed of omnivores
OM_Rich	Richness composed of omnivores
pOM_Rich	Percentage of total richness composed of omnivores

Appendix 1-9. Benthic macro-invertebrate metrics used in data analysis for 30 study sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[Detrended Correspondence Analysis (DCA) for richest-targeted-habitat, percent density, all species, all sites. Except for DCA metrics, all metric abbreviations are from Cuffney (2003).]

Metric abbreviation	Definition
	Functional group metrics (continued)
PA_Abund	Total abundance composed of parasites
pPA_Abund	Percentage of total abundance composed of parasites
PA_Rich	Richness composed of parasites
pPA_Rich	Percentage of total richness composed of parasites
PI_Abund	Total abundance composed of piercers
pPI_Abund	Percentage of total abundance composed of piercers
PI_Rich	Richness composed of piercers
pPI_Rich	Percentage of total richness composed of piercers
PR_Abund	Total abundance composed of predators
pPR_Abund	Percentage of total abundance composed of predators
PR_Rich	Richness composed of predators
pPR_Rich	Percentage of total richness composed of predators
SC_Abund	Total abundance composed of scrapers
pSC_Abund	Percentage of total abundance composed of scrapers
SC_Rich	Richness composed of scrapers
pSC_Rich	Percentage of total richness composed of scrapers
SH_Abund	Total abundance composed of shredders
pSH_Abund	Percentage of total abundance composed of shredders
SH_Rich	Richness composed of shredders
pSH_Rich	Percentage of total richness composed of shredders
	Percentage abundance of dominant taxa
DOM1	Percentage of total abundance represented by the most abundant taxon
DOM2	Percentage of total abundance represented by the two most abundant taxa
DOM3	Percentage of total abundance represented by the three most abundant taxa
DOM4	Percentage of total abundance represented by the four most abundant taxa
DOM5	Percentage of total abundance represented by the five most abundant taxa
	Diversity Index metrics
Margalef	Margalef diversity
ShanDiv	Shannon diversity

Appendix 1-10. Fish metrics used in data analysis for 30 study sites in the Milwaukee to Green Bay, Wis., study area.

[DCA, detrended correspondance analysis]

Metric abbreviation	Metric definition	Reference[1]
	DCA metrics	
fDCA Axis 1	Fish DCA Axis 1 site scores	
fDCA Axis 2	Fish DCA Axis 2 site scores	
fDCA Axis 3	Fish DCA Axis 3 site scores	
fDCA Axis 4	Fish DCA Axis 4 site scores	
	Index of Biotic Integrity	
IBI_Score	Index of Biotic Integrity score, Wisconsin	a, b
IBI Rating	Index of Biotic Integrity rating, Wisconsin	a, b
	Abundance and richness metrics	
CARN_LY	Number of individual fish that are top carnivores	a
DARTER_LY	Number of darter species	a
INSC_LY	Number of individual fish that are insectivorous	a
LITHO_LY	Number of individual fish that are simple lithophils	a
NATIVE_LY	Number of native Wisconsin species	a
OMNI_LY	Number of individual fish that are omnivorous	a
SUCKER_LY	Number of sucker species	a
SUNFSH_LY	Number of sunfish species	a
TAXAfish	Richness of fish taxa in sample (number of unique, non-ambiguous taxa)	
ABUNfish	Total number of individual fish in sample	
	Tolerance metrics	
INTOL_LY	Number of fish species intolerant of environmental degradation	a
TOLR_LY	Number of individual fish tolerant of environmental degradation	a
INTMfshE	Percentage of total abundance composed of intermediate-tolerance fish	c
SENSfshE	Percentage of total abundance composed of intolerant fish	c
TOLRfshE	Percentage of total abundance composed of tolerant fish	c
	Trophic ecology metrics	
GENRfshE	Percentage of total abundance composed of fish that are generalist feeders	c
INSCfshE	Percentage of total abundance composed of fish that are insectivorous feeders	c
OMNIfshE	Percentage of total abundance composed of fish that are omnivorous feeders	c
PISCfshE	Percentage of total abundance composed of fish that are piscivorous feeders	c
CARNfish	Percentage of total abundance composed of fish that are carnivorous feeders	d
DETRfish	Percentage of total abundance composed of fish that are detrivorous feeders	d

[1] Metrics (not metric abbreviations) are from:

a. Lyons, 1992
b. Lyons and others, 1996
c. Barbour and others, 1999
d. Goldstein and Meador, 2004

Appendix 1-10. Fish metrics used in data analysis for 30 sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[DCA, detrended correspondance analysis]

Metric abbreviation	Metric definition	Reference[1]
HERBfish	Percentage of total abundance composed of herbivores	d
INVTfish	Percentage of total abundance composed of invertivores	d
	Substrate preference metrics	
BOLDfish	Percentage of total abundance composed of fish that prefer boulder substrate	d
COBBfish	Percentage of total abundance composed of fish that prefer cobble/rubble substrate	d
GRVLfish	Percentage of total abundance composed of fish that prefer gravel substrate	d
SANDfish	Percentage of total abundance composed of fish that prefer sand substrate	d
MUDfish	Percentage of total abundance composed of fish that prefer mud (silt, clay, detritus)	d
VEGEfish	Percentage of total abundance composed of fish that prefer vegetation	d
VRSBfish	Percentage of total abundance composed of fish that prefer variable substrates	d
	Geomorphic preference metrics	
RIFFfish	Percentage of total abundance composed of fish that prefer riffles	d
POOLfish	Percentage of total abundance composed of fish that prefer pools	d
RUNfish	Percentage of total abundance composed of fish that prefer runs or main channels	d
BKWTfish	Percentage of total abundance composed of fish that prefer backwaters	d
VRGEfish	Percentage of total abundance composed of fish that prefer variable geomorphic types	d
	Locomotion morphology metrics	
CRSRfish	Percentage of total abundance composed of fish that are cruisers	d
ACCLfish	Percentage of total abundance composed of fish that are accelerators	d
HUGGfish	Percentage of total abundance composed of fish that are benthic high-velocity huggers	d
CREEPfish	Percentage of total abundance composed of fish that are benthic low-velocity creepers	d
MANVfish	Percentage of total abundance composed of fish that are maneuverers	d
	Reproductive strategy metrics	
BRDCfish	Percentage of total abundance composed of fish that are broadcasters	d
SIMPfish	Percentage of total abundance composed of fish that are simple nesters	d
COMPfish	Percentage of total abundance composed of fish that are complex nester-guarders	d
MIGRfish	Percentage of total abundance composed of fish that are migratory	d

[1] Metrics (not metric abbreviations) are from:

a. Lyons, 1992
b. Lyons and others, 1996
c. Barbour and others, 1999
d. Goldstein and Meador, 2004

Appendix 2. Streamwater analytes analyzed in samples from the Milwaukee to Green Bay, Wis., study area.

[mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius]

Analyte	Parameter code	Reporting level
Nutrients		
Nitrogen, ammonia	00608	0.04 mg/L
Nitrogen, nitrite	00613	.008 mg/L
Nitrogen, nitrite+nitrate	00631	.060 mg/L
Total nitrogen (NH_3 + NO_2 + NO_3 + organic N)	62855	.06 mg/L
Phosphorous, phosphate, orthophosphate	00671	.006 mg/L
Total phosphorous	00665	.004 mg/L
Ions		
Chloride	00940	.20 mg/L
Sulfate	00945	.18 mg/L
Carbon		
Dissolved organic carbon	00681	.33 mg/L
Particulate inorganic carbon	00688	.12 mg/L
Total particulate carbon	00694	.12 mg/L
Particulate organic carbon	00689	.12 mg/L
Total particulate nitrogen	49570	.022 mg/L
Pesticides and degradates		
1-Napthol	49295	.0882 µg/L
2-Chloro-2,3-diethylacetanilide	61618	.005 µg/L
2-Ethyl-6-methylaniline	61620	.0045 µg/L
3,4-Dichloraniline	61625	.0045 µg/L
4-Chloro-2-methylphenol	61633	.0057 µg/L
Acetochlor	49260	.006 µg/L
Alachlor	46342	.005 µg/L
2,6-Diethylaniline	82660	.006 µg/L
Atrazine	39632	.007 µg/L
Aziniphos-methyl	82686	.05 µg/L
Aziniphos-methyl-oxon	61635	.07 µg/L
Benfluralin	82673	.010 µg/L
Carbaryl	82680	.041 µg/L
Chlorpyrifos	38933	.005 µg/L
Chlorpyrofos-oxygen analog	61636	.0562 µg/L
Cis-Permethrin	82687	.006 µg/L
Cyfluthrin	61585	.008 µg/L
Cypermethrin	61586	.0086 µg/L
Dacthal	82682	.003 µg/L
2-Chloro-4-isopropylamino-6-amino-s-triazine (CIAT)	04040	.006µg/L
Diazinon	39572	.005 µg/L
Diazinon, oxygen analog	61638	.006 µg/L
Dichlorvos	38775	.0118 µg/L
Dicrotophos	38454	.0843 µg/L
Dieldrin	39381	.009 µg/L
Dimethoate	82662	.0061 µg/L
Ethion	82346	.004 µg/L
Ethion monoxon	61644	.002 µg/L
Fenamiphos	61591	.029 µg/L

Appendix 2. Streamwater analytes analyzed in samples from the Milwaukee to Green Bay, Wis., study area—Continued.

[mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius]

Analyte	Parameter code	Reporting level
Pesticides and degradates (continued)		
Fenamiphos sulfone	61645	.0491 µg/L
Fenamiphos sulfoxide	61646	.0387 µg/L
Desulfinylpronil amide	62169	.029 µg/L
Fipronil sulfide	62167	.013 µg/L
Fipronil sulfone	62168	.024 µg/L
Desulfinylfipronel	62170	.012 µg/L
Fipronil	62166	.016 µg/L
Fonofos	04095	.003 µg/L
Fonofos, oxygen analog	61649	.0029 µg/L
Hexazinone	04025	.0129 µg/L
Iprodione	61593	.387 µg/L
Isofenphos	61594	.0034 µg/L
Malaoxon	61652	.0298 µg/L
Malathion	39532	.0027 µg/L
Metalaxyl	61596	.0051 µg/L
Methidathion	61598	.0058 µg/L
Parathion-methyl	82667	.015 µg/L
Metolachlor	39415	.006 µg/L
Metribuzin	82630	.006 µg/L
Myclobutanil	61599	.008 µg/L
Paraoxon-methyl	61664	.0299 µg/L
Pendimethalin	82683	.022 µg/L
Phorate	82664	.011 µg/L
Phorate, oxygen analog	61666	.1048 µg/L
Phosmet	61601	.0079 µg/L
Phosmet, oxon	61668	.0511 µg/L
Prometon	04037	.010 µg/L
Prometryn	04036	.0054 µg/L
Propyzamide	82676	.004 µg/L
Simazine	04035	.005 µg/L
Tebuthiuron	82670	.016 µg/L
Terbufos	82675	.017 µg/L
Terbufos, oxygen analog sulfone	61674	.0676 µg/L
Terbuthylazine	04022	.0102 µg/L
Trifluralin	82661	.009 µg/L
Sediment		
Suspended sediment concentration	80154	1 mg/L
Field Parameters		
pH	00400	Standard units
Specific conductance	00095	µS/cm at 25°C
Dissolved oxygen	00300	mg/L
Dissolved oxygen, percent saturation	00301	Percent
Alkalinity, water filtered, incremental titration, field	39086	mg/L
Bicarbonate, water filtered, incremental titration, field	00453	mg/L
Carbonate, water filtered, incremental titration, field	00452	mg/L

Appendix 3. Spearman rank correlations between richest-targeted habitat (RTH) algal metrics and environmental characteristics for 30 sites in the Milwaukee to Green Bay, Wis., study area.

[QW, water-quality samples; GIS, geographic information systems; Dark green indicates $p \leq 0.001$; green indicates $p \leq 0.01$; light green indicates $p \leq 0.05$; characteristic and metric definitions are listed in appendix 1.]

	QW summer characteristics					QW spring characteristics				GIS characteristics					
Metric abbreviation	BICARB	ALK	PTIINV	ORTHOP	NOX	CHLOR	DISORGC	SPCOND	SULFA	PMRLC42	PNLCD9	PERH	NLCD.IS	HHDEN	RDAREADEN
aDCA Axis 1_R	0.03	0.02	-0.04	-0.30	-0.13	0.49	-0.18	0.57	0.52	-0.35	-0.27	-0.08	0.43	0.44	0.42
aDCA Axis 2_R	-.51	-.48	.39	.58	-.19	-.05	-.21	-.07	-.06	-.14	-.27	-.28	.03	-.04	-.01
aDCA Axis 3_R	-.28	-.29	-.08	-.16	.05	.44	-.33	.53	.44	-.41	-.53	-.38	.50	.44	.52
aDCA Axis 4_R	-.02	.01	.14	-.01	-.23	.03	-.21	-.05	.08	-.36	-.24	-.32	.07	-.04	.04
BioDtms_R	.48	.51	-.21	-.36	.08	-.33	.22	-.27	-.19	.10	.33	.29	-.31	-.31	-.29
CP_R	.16	.17	-.15	-.38	-.27	.29	.01	.41	.40	-.44	-.31	-.28	.21	.18	.18
SiltIdx_R	-.64	-.61	.43	.32	-.44	.51	-.45	.47	.53	-.63	-.59	-.53	.48	.40	.40
SP_BM_R	.63	.61	-.51	-.28	.32	-.61	.50	-.55	-.52	.74	.68	.69	-.64	-.58	-.56
SP_AM_R	-.63	-.61	.42	.27	-.41	.62	-.56	.54	.61	-.77	-.66	-.70	.67	.61	.58
SP_PS_R	-.05	-.06	-.08	-.40	-.16	.40	-.41	.49	.38	-.32	-.40	-.14	.46	.41	.47
ON_AH_R	.68	.66	-.56	-.34	.35	-.57	.54	-.49	-.50	.70	.62	.65	-.60	-.54	-.50
ON_HF_R	-.71	-.68	.50	.32	-.42	.56	-.56	.49	.49	-.69	-.64	-.64	.59	.53	.50
ON_NH_R	-.72	-.69	.48	.30	-.42	.57	-.56	.50	.50	-.70	-.64	-.64	.60	.54	.52
TR_MT_R	.36	.35	-.22	-.24	.34	-.04	.12	.03	-.03	-.01	-.14	.12	.01	-.02	.06
TR_ET_R	-.34	-.35	.14	.46	-.14	-.14	.04	-.25	-.15	.21	.22	.17	-.16	-.10	-.15
TR_PT_R	-.14	-.17	-.16	-.36	-.34	.41	-.26	.51	.48	-.30	-.42	-.05	.37	.33	.37
TR_EY_R	.39	.36	-.24	-.46	.17	.18	-.01	.28	.18	-.05	-.18	-.11	.17	.19	.16
TR_E_R	-.37	-.34	.32	.55	-.12	-.19	.02	-.31	-.17	.03	.17	.01	-.16	-.17	-.16
EUTROPHC_R	-.40	-.37	.34	.54	-.15	-.16	-.01	-.28	-.17	.01	.14	-.01	-.12	-.12	-.11
PC_LT_R	-.62	-.60	.42	.21	-.31	.68	-.57	.60	.60	-.82	-.70	-.74	.74	.69	.66
PC_SN_R	.65	.62	-.48	-.28	.36	-.60	.55	-.55	-.51	.74	.70	.71	-.63	-.57	-.56
PT_VT_R	-.57	-.54	.62	.47	-.15	.26	-.44	.24	.14	-.36	-.51	-.53	.32	.23	.25
PT_LA_R	.59	.58	-.31	-.02	.31	-.57	.44	-.60	-.48	.62	.74	.58	-.59	-.52	-.59
SL_FB_R	.72	.70	-.50	-.28	.36	-.68	.60	-.59	-.62	.71	.64	.66	-.70	-.64	-.61
SL_BF_R	-.72	-.70	.48	.26	-.39	.67	-.63	.57	.61	-.74	-.66	-.69	.72	.66	.64
SL_HB_R	-.72	-.70	.46	.26	-.38	.67	-.62	.58	.61	-.74	-.66	-.70	.72	.66	.64
PH_CN_R	.22	.19	-.07	-.02	.18	.10	.00	.26	.11	.19	-.13	.11	-.01	-.02	.01
PH_LP_R	-.26	-.23	.12	.30	-.14	-.10	.09	-.24	-.07	-.13	.13	-.02	-.06	-.05	-.11
PH_IF_R	.24	.20	-.30	-.52	.06	.16	-.15	.20	.12	-.01	-.04	-.08	.22	.25	.26
BS_BE_R	.00	-.01	.00	.32	-.12	-.23	.15	-.29	-.04	.26	.21	.29	-.28	-.23	-.26
OT_AH_R	.24	.22	-.07	-.36	.28	.09	-.08	.17	.12	-.05	-.06	-.01	.14	.10	.14
OT_FH_R	.64	.62	-.36	-.11	.22	-.68	.56	-.63	-.58	.76	.69	.73	-.72	-.64	-.67
OT_MD_R	-.62	-.62	.22	.18	-.26	.70	-.46	.62	.62	-.72	-.63	-.70	.72	.67	.67

Appendix 3. Spearman rank correlations between richest-targeted habitat (RTH) algal metrics and environmental characteristics for 30 study sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[QW, water-quality samples; GIS, geographic information systems; Dark green indicates p ≤ 0.001; green indicates p ≤ 0.01; light green indicates p ≤ 0.05; characteristic and metric definitions are listed in appendix 1.]

Metric abbreviation	Habitat characteristics							Hydrologic (pre-ice period) characteristics							
	BFAREADA	BFAREADNO	BFDEPDA	BFDNOP	BFWIDDA	CHANSHCO	WETVOLDA	day_pctchange_pre	max_totrise_pre	periodr3_pre	periodr9_pre	periodf3_pre	periodf5_pre	periodf7_pre	periodf9_pre
aDCA Axis 1_R	0.26	0.24	0.28	-0.13	0.43	0.64	0.18	0.71	0.30	0.69	0.55	0.65	0.62	0.58	0.56
aDCA Axis 2_R	-.37	-.22	-.21	.22	-.44	-.16	-.35	.37	.46	.35	.39	.44	.53	.54	.55
aDCA Axis 3_R	.31	.32	.44	.24	.25	.14	.25	.36	-.10	.22	-.06	.12	.12	.13	.01
aDCA Axis 4_R	-.01	.05	.18	.11	-.05	.07	-.19	.06	-.08	.12	.04	.11	.06	.07	-.04
BioDtms_R	-.07	-.16	-.11	-.35	.06	-.16	-.07	-.44	-.36	-.37	-.26	-.51	-.50	-.44	-.46
CP_R	.19	.16	.40	-.13	.30	.23	.17	.08	.14	.00	.02	-.07	-.03	.00	-.04
SiltIdx_R	-.07	.01	.03	.46	-.25	.25	-.06	.38	.53	.34	.45	.55	.49	.51	.51
SP_BM_R	-.05	-.16	-.18	-.43	.07	-.26	-.08	-.50	-.50	-.47	-.51	-.63	-.54	-.58	-.57
SP_AM_R	.05	.18	.16	.41	-.09	.23	.02	.55	.48	.53	.58	.70	.63	.62	.61
SP_PS_R	.41	.33	.40	.05	.43	.18	.45	.34	.56	.32	.39	.44	.44	.48	.55
ON_AH_R	-.04	-.17	-.13	-.42	.10	-.19	-.01	-.54	-.36	-.48	-.43	-.57	-.47	-.49	-.46
ON_HF_R	.00	.12	.12	.39	-.15	.18	-.06	.52	.33	.49	.44	.56	.48	.46	.44
ON_NH_R	.00	.12	.13	.38	-.14	.19	-.05	.51	.38	.49	.45	.58	.49	.49	.47
TR_MT_R	.42	.27	.40	.30	.36	.08	.56	-.05	.13	-.06	-.04	-.17	-.04	.03	.03
TR_ET_R	-.46	-.38	-.43	.01	-.52	-.22	-.46	-.10	-.27	.04	-.03	-.09	-.12	-.17	-.15
TR_PT_R	.21	.16	.40	-.05	.28	.17	.26	.36	.65	.18	.18	.24	.26	.29	.37
TR_EY_R	.53	.45	.44	-.02	.56	.22	.52	.18	.24	-.10	-.01	.04	.05	.08	.10
TR_E_R	-.52	-.41	-.43	.08	-.57	-.25	-.50	-.16	-.32	.05	-.04	-.06	-.08	-.13	-.16
EUTROPHC_R	-.49	-.38	-.38	.08	-.53	-.22	-.45	-.13	-.29	.10	.00	-.03	-.04	-.09	-.12
PC_LT_R	.16	.27	.23	.46	.01	.31	.14	.57	.56	.54	.60	.73	.66	.69	.67
PC_SN_R	-.05	-.16	-.18	-.43	.09	-.27	-.03	-.52	-.54	-.45	-.52	-.66	-.56	-.59	-.59
PT_VT_R	.00	.10	.09	.45	-.16	.10	.02	.39	.25	.34	.32	.45	.33	.35	.36
PT_LA_R	-.14	-.21	-.40	-.30	-.10	-.35	-.14	-.44	-.56	-.37	-.43	-.53	-.44	-.51	-.52
SL_FB_R	-.09	-.22	-.15	-.35	.02	-.21	-.02	-.53	-.38	-.51	.55	-.69	-.60	-.60	-.57
SL_BF_R	.08	.22	.20	.34	-.02	.25	-.01	.54	.35	.55	-.53	.69	.62	.61	.57
SL_HB_R	.09	.22	.20	.35	-.02	.24	.01	.52	.36	.55	-.55	.70	.62	.61	.57
PH_CN_R	.42	.32	.27	.09	.39	.10	.49	-.04	.34	-.14	.02	.06	.01	.04	.14
PH_LP_R	-.53	-.42	-.41	-.01	-.52	-.05	-.55	.10	-.23	.21	.02	.01	.10	.02	-.04
PH_IF_R	.48	.38	.40	-.02	.48	-.10	.53	.01	.20	.02	.13	.14	.09	.18	.18
BS_BE_R	-.45	-.42	-.44	.01	-.48	-.20	-.31	-.29	.13	-.26	-.06	-.12	-.04	-.06	-.01
OT_AH_R	.54	.47	.41	.08	.56	-.01	.55	.00	.06	-.01	.04	.06	.02	.15	.12
OT_FH_R	-.18	-.25	-.25	-.42	-.02	-.31	-.13	-.53	-.49	-.49	-.56	-.69	-.58	-.63	-.61
OT_MD_R	.17	.25	.20	.43	-.00	.37	.12	.52	.45	.55	.64	.69	.60	.60	.60

Appendix 3. Spearman rank correlations between richest-targeted habitat (RTH) algal metrics and environmental characteristics for 30 study sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[QW, water-quality samples; GIS, geographic information systems; Dark green indicates p ≤ 0.001; green indicates p ≤ 0.01; light green indicates p ≤ 0.05; characteristic and metric definitions are listed in appendix 1.]

Metric abbreviation	Hydrologic (post-ice period) characteristics							
	cumulative_ change_pst	periodr1_pst	periodr5_pst	periodr7_pst	periodr9_pst	periodf5_pst	periodf9_pst	max_durrise_pst
aDCA Axis 1_R	0.23	-0.51	0.53	0.68	0.67	0.48	0.50	0.56
aDCA Axis 2_R	.38	.20	.43	.42	.34	.40	.43	-.12
aDCA Axis 3_R	-.12	-.46	.15	.32	.36	.09	.12	-.24
aDCA Axis 4_R	-.23	-.13	-.32	-.24	-.20	-.26	-.17	.16
BioDtms_R	.09	.24	.05	-.09	-.12	-.08	-.13	-.01
CP_R	.13	.19	.30	.20	.17	.07	.04	-.37
SiltIdx_R	.12	-.51	.30	.48	.46	.30	.38	-.01
SP_BM_R	-.15	.51	-.40	-.59	-.58	-.38	-.43	.11
SP_AM_R	.17	-.60	.53	.69	.68	.49	.52	-.19
SP_PS_R	.40	-.15	.35	.47	.41	.48	.57	-.12
ON_AH_R	-.07	.59	-.41	-.56	-.59	-.32	-.36	.20
ON_HF_R	.03	-.59	.45	.57	.59	.32	.34	-.33
ON_NH_R	.06	-.60	.44	.58	.60	.34	.37	-.26
TR_MT_R	.19	.28	.11	.09	.01	.04	.06	-.10
TR_ET_R	-.28	-.28	-.03	-.05	-.02	-.10	-.14	-.06
TR_PT_R	.30	.00	.24	.34	.28	.30	.34	-.15
TR_EY_R	.30	.25	.07	.05	.02	.11	.12	.00
TR_E_R	-.35	-.30	-.10	-.06	-.02	-.14	-.17	.05
EUTROPHC_R	-.30	-.31	-.03	.01	.04	-.09	-.12	-.02
PC_LT_R	.25	-.54	.52	.70	.69	.50	.54	-.12
PC_SN_R	-.16	.54	-.41	-.59	-.59	-.39	-.45	.08
PT_VT_R	-.02	-.46	.12	.28	.30	.16	.24	.02
PT_LA_R	-.27	.20	-.37	-.48	-.48	-.36	-.39	.09
SL_FB_R	-.13	.59	-.51	-.67	-.68	-.50	-.52	.19
SL_BF_R	.13	-.57	.54	.69	.70	.51	.53	-.23
SL_HB_R	.15	-.56	.55	.70	.70	.52	.54	-.21
PH_CN_R	.11	.12	-.03	-.04	-.04	.02	.00	.02
PH_LP_R	-.29	-.16	-.08	-.06	-.05	-.16	-.18	-.11
PH_IF_R	.65	.07	.50	.48	.48	.54	.59	.02
BS_BE_R	-.32	-.19	-.43	-.30	-.36	-.26	-.23	.34
OT_AH_R	.47	.16	.22	.24	.23	.33	.39	.16
OT_FH_R	-.28	.48	-.52	-.68	-.68	-.53	-.56	.15
OT_MD_R	.19	-.37	.63	.69	.66	.54	.49	-.31

Appendix 4. Spearman rank correlations between depositional-targeted habitat (DTH) algal metrics and environmental characteristics for 30 study sites in the Milwaukee to Green Bay, Wis., study area.

[QW, water quality sample; GIS, geographic information system. Dark green indicates p ≤ 0.001; green indicates p ≤ 0.01; light green indicates p ≤ 0.05. Metric and characteristic abbreviations are listed in appendix 1.]

Metric abbreviation	QW summer characteristics					QW spring characteristics							
	SPCOND	CHLOR	BICARBON	ALK	SUSSED	DISORGC	NUMP	NUMH	NOX	NITRATE	TOTALN	BICARBON	ALK
aDCA Axis 1_D	0.26	0.49	-0.56	-0.54	-0.10	-0.63	0.47	0.55	0.58	0.57	0.54	0.34	0.37
aDCA Axis 2_D	-.06	-.05	-.19	-.20	.00	-.08	.08	.09	-.19	-.18	-.25	.19	.19
aDCA Axis 3_D	.40	.35	.02	-.01	.21	-.07	.12	.06	-.10	-.09	-.06	-.13	-.10
aDCA Axis 4_D	.64	.56	.14	.16	.53	-.28	.31	.25	.16	.16	.19	.00	.03
BioDtms_D	-.12	-.26	.26	.28	.12	.24	-.29	-.31	-.37	-.37	-.32	-.41	-.44
NumTax_all_D	-.24	-.33	.42	.41	.00	.54	-.38	-.37	-.29	-.28	-.22	-.02	-.06
SiltIdx_D	.05	.10	-.17	-.13	.04	-.32	.32	.38	.38	.39	.46	.12	.12
SP_OL_D	.05	.11	-.06	-.03	-.07	-.15	.14	.16	.24	.23	.22	.36	.34
SP_BM_D	-.13	-.30	.26	.22	-.03	.43	-.40	-.49	-.43	-.42	-.42	-.25	-.26
SP_AM_D	.13	.30	-.31	-.27	.05	-.51	.44	.51	.48	.48	.49	.14	.15
ON_AH_D	-.05	-.29	.52	.49	.16	.60	-.32	-.40	-.51	-.51	-.41	-.42	-.45
ON_HF_D	.03	.30	-.56	-.54	-.15	-.58	.31	.41	.52	.51	.40	.33	.36
ON_NH_D	.00	.28	-.57	-.54	-.18	-.58	.30	.39	.52	.51	.40	.38	.40
NF_YS_D	-.64	-.45	-.23	-.23	-.50	-.04	-.15	-.07	.15	.15	.13	.24	.22
TR_OM_D	-.05	-.27	.69	.68	.26	.38	-.62	-.62	-.14	-.13	-.14	.23	.20
TR_ET_D	.14	.27	-.53	-.54	-.34	-.03	.60	.59	.36	.35	.38	-.30	-.26
TR_PT_D	-.25	-.10	-.18	-.14	-.14	-.47	.02	.08	.26	.25	.25	.33	.32
TR_EY_D	.15	-.03	.50	.48	.51	.18	-.54	-.54	-.41	-.40	-.43	.32	.31
TR_E_D	-.03	.10	-.50	-.49	-.47	-.12	.57	.54	.34	.34	.38	-.38	-.36
EUTROPHIC_D	-.10	.06	-.52	-.52	-.52	-.14	.56	.54	.35	.35	.38	-.34	-.33
PC_MT_D	-.04	.20	-.30	-.28	-.22	-.32	.14	.22	.44	.43	.37	.57	.58
PC_LT_D	-.05	.12	-.28	-.24	.03	-.35	.41	.47	.30	.30	.30	.00	.00
PC_SN_D	-.03	-.23	.31	.27	.00	.39	-.38	-.48	-.41	-.41	-.39	-.23	-.24
PT_VT_D	-.16	.14	-.44	-.41	-.28	-.38	.13	.23	.33	.32	.23	.53	.54
PT_LA_D	-.14	-.26	.10	.08	-.08	.18	-.28	-.34	-.24	-.24	-.27	-.35	-.33
SL_FB_D	-.16	-.39	.59	.55	.12	.66	-.66	-.71	-.51	-.50	-.53	.04	.02
SL_BF_D	.21	.43	-.59	-.56	-.09	-.64	.71	.75	.51	.50	.52	-.11	-.08
SL_HB_D	.19	.40	-.58	-.55	-.09	-.64	.71	.75	.48	.48	.51	-.12	-.10
PH_CN_D	-.16	-.03	-.08	-.04	-.16	-.26	-.03	.01	.26	.26	.20	.50	.48
PH_LP_D	.02	-.10	.09	.08	-.06	.42	-.03	-.08	-.20	-.19	-.12	-.52	-.49
BS_BE_D	.64	.49	.17	.19	.37	-.16	.16	.06	.05	.06	.15	-.10	-.07
MS_OW_D	-.46	-.61	.21	.20	-.27	.44	-.31	-.35	-.25	-.25	-.26	-.17	-.20
OT_FH_D	-.30	-.52	.37	.34	-.11	.57	-.42	-.55	-.54	-.53	-.51	-.24	-.26

Appendix 4. Spearman rank correlations between depositional-targeted habitat (DTH) algal metrics and environmental characteristics for 30 study sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[QW, water quality sample; GIS, geographic information system. Dark green indicates p ≤ 0.001; green indicates p ≤ 0.01; light green indicates p ≤ 0.05. Metric and characteristic abbreviations are listed in appendix 1.]

Metric abbreviation	GIS characteristics						Habitat characteristics						
	PNLCD23	PP.SH95	PNLCD24	PNLCD9	PNLCD81	NLCD.IS	RCHSLOPE	D50crit	RUN	BFSHEAR	GCUALT	CANANG	WETWDRAT
aDCA Axis 1_D	0.66	-0.68	0.63	-0.80	-0.61	0.62	-0.46	-0.37	0.57	-0.41	0.41	-0.08	-0.42
aDCA Axis 2_D	.04	-.11	.04	.06	.02	.04	-.01	-.09	-.20	-.02	.04	-.07	.04
aDCA Axis 3_D	.34	-.14	.33	-.22	-.14	.37	.29	.28	-.19	.21	-.30	-.41	.11
aDCA Axis 4_D	.38	-.18	.42	-.32	-.34	.40	-.03	-.06	.10	-.08	-.10	-.50	.02
BioDtms_D	-.39	.49	-.38	.42	.22	-.34	.24	.16	-.45	.28	-.30	.30	.47
NumTax_all_D	-.53	.62	-.56	.53	.39	-.50	.23	.13	-.32	.21	-.06	.01	-.08
SiltIdx_D	.21	-.21	.19	-.29	-.20	.18	-.38	-.35	.35	-.32	.34	.08	-.28
SP_OL_D	.05	-.31	.10	-.17	-.13	.02	-.64	-.64	.55	-.61	.56	.08	-.28
SP_BM_D	-.38	.35	-.36	.54	.45	-.34	.55	.47	-.48	.50	-.45	-.03	.43
SP_AM_D	.51	-.34	.47	-.48	-.54	.47	-.38	-.31	.38	-.29	.32	.04	-.28
ON_AH_D	-.57	.68	-.54	.63	.52	-.53	.38	.29	-.48	.35	-.34	-.07	.14
ON_HF_D	.65	-.70	.62	-.63	-.60	.63	-.30	-.19	.39	-.26	.19	.11	-.07
ON_NH_D	.64	-.69	.60	-.62	-.58	.61	-.33	-.23	.41	-.30	.24	.15	-.10
NF_YS_D	-.22	.03	-.31	-.04	.22	-.24	-.16	-.07	.20	-.04	.31	.52	-.32
TR_OM_D	-.46	.36	-.44	.34	.42	-.43	.18	.07	-.16	.14	.03	.00	.04
TR_ET_D	.19	-.06	.25	-.15	-.11	.20	-.14	-.06	.29	-.07	.08	-.39	-.03
TR_PT_D	.17	-.30	.11	-.30	-.23	.13	-.41	-.38	.32	-.34	.44	.51	-.15
TR_EY_D	-.08	-.01	-.11	.06	.10	-.07	.24	.16	-.34	.11	-.21	-.06	-.04
TR_E_D	.11	.06	.15	-.03	-.07	.11	-.17	-.08	.24	-.03	.12	-.07	.05
EUTROPHIC_D	.09	.03	.12	-.05	-.06	.09	-.21	-.11	.27	-.05	.16	.00	.00
PC_MT_D	.25	-.47	.26	-.44	-.27	.23	-.62	-.58	.59	-.66	.56	.09	-.36
PC_LT_D	.42	-.27	.34	-.48	-.47	.39	-.21	-.14	.22	-.19	.17	.11	-.35
PC_SN_D	-.35	.35	-.30	.60	.37	-.31	.44	.36	-.50	.40	-.43	-.03	.51
PT_VT_D	.36	-.53	.33	-.47	-.36	.34	-.50	-.42	.43	-.53	.38	.22	-.28
PT_LA_D	-.18	.16	-.15	.36	.22	-.17	.49	.50	-.42	.47	-.49	-.04	.53
SL_FB_D	-.64	.46	-.61	.50	.68	-.62	.29	.22	-.26	.23	-.16	-.17	.08
SL_BF_D	.67	-.44	.65	-.50	-.71	.66	-.21	-.13	.21	-.16	.06	.06	-.02
SL_HB_D	.65	-.40	.63	-.47	-.68	.63	-.23	-.15	.18	-.17	.08	.08	-.02
PH_CN_D	.08	-.35	.07	-.17	-.11	.05	-.53	-.55	.45	-.51	.56	.31	-.21
PH_LP_D	-.23	.48	-.23	.25	.27	-.20	.44	.48	-.31	.43	-.41	-.31	.15
BS_BE_D	.21	-.02	.23	-.05	-.19	.20	.12	.08	-.04	-.01	-.11	-.30	.06
MS_OW_D	-.58	.48	-.52	.46	.50	-.55	.07	.08	-.35	.17	-.10	.23	.19
OT_FH_D	-.59	.50	-.59	.71	.64	-.57	.50	.45	-.46	.50	-.37	.01	.38

Appendix 4. Spearman rank correlations between depositional-targeted habitat (DTH) algal metrics and environmental characteristics for 30 study sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[QW, water quality sample; GIS, geographic information system. Dark green indicates p ≤ 0.001; green indicates p ≤ 0.01; light green indicates p ≤ 0.05. Metric and characteristic abbreviations are listed in appendix 1.]

Metric abbreviation	Hydrologic (pre-ice period) characteristics											Hydrologic (post-ice period) characteristics					
	pct_10n_pre	periodr3_pre	periodr5_pre	periodr7_pre	periodr9_pre	periodf3_pre	periodf5_pre	periodf7_pre	periodf9_pre	mxh_95_pre	mxl_25_pre	periodr1_pst	periodr5_pst	periodr7_pst	periodr9_pst	mdh_95_pst	mdl_25_pst
aDCA Axis 1_D	-0.32	0.26	0.17	0.21	0.20	0.14	0.12	0.05	0.09	-0.21	0.10	0.04	-0.03	-0.11	-0.13	0.13	-0.09
aDCA Axis 2_D	.04	.64	.64	.52	.40	.61	.65	.61	.57	-.52	-.04	-.40	.47	.63	.66	-.56	.16
aDCA Axis 3_D	.28	.10	.08	.12	.24	.27	.23	.30	.35	-.21	-.02	-.08	.20	.26	.23	-.04	.41
aDCA Axis 4_D	.07	.08	.11	.03	.11	-.07	.01	.04	-.09	-.24	-.08	.12	.15	.16	.12	-.23	-.19
BioDtms_D	.11	-.46	-.46	-.46	-.29	-.42	-.45	-.39	-.43	.13	-.17	.38	-.19	-.30	-.34	.05	-.15
NumTax_all_D	.12	-.42	-.37	-.45	-.45	-.62	-.52	-.46	-.51	.15	-.24	.73	-.40	-.51	-.56	.39	-.34
SiltIdx_D	.21	.20	.26	.18	.23	.27	.41	.45	.44	-.27	-.12	-.08	.08	.24	.19	-.21	.03
SP_OL_D	.40	.08	.16	.18	.04	.07	.05	.11	.10	-.03	-.24	-.23	.17	.20	.23	-.23	.06
SP_BM_D	-.41	-.42	-.54	-.44	-.40	-.49	-.56	-.60	-.53	.48	.16	.13	-.36	-.48	-.48	.48	-.09
SP_AM_D	.32	.45	.55	.37	.38	.39	.52	.58	.46	-.59	-.25	-.12	.40	.54	.50	-.56	.10
ON_AH_D	-.42	-.62	-.65	-.62	-.62	-.64	-.67	-.69	-.68	.34	.27	.47	-.52	-.62	-.62	.60	-.05
ON_HF_D	.37	.71	.70	.67	.69	.66	.67	.66	.65	-.36	-.29	-.46	.64	.70	.68	-.69	.07
ON_NH_D	.40	.68	.67	.64	.68	.63	.64	.64	.63	-.34	-.33	-.45	.63	.68	.66	-.66	.06
NF_YS_D	.46	-.13	-.13	.00	.11	-.12	-.17	-.10	-.11	.32	-.37	.07	-.07	-.08	-.13	.18	-.12
TR_OM_D	-.11	-.35	-.39	-.37	-.45	-.62	-.56	-.59	-.58	.38	-.23	.44	-.30	-.42	-.42	.38	-.68
TR_ET_D	-.49	.40	.38	.28	.18	.41	.39	.30	.30	-.26	.37	-.16	.02	.12	.17	-.02	.62
TR_PT_D	.58	.05	.13	.13	.13	.06	.14	.17	.14	-.06	-.64	-.11	.24	.26	.22	-.28	-.18
TR_EY_D	.23	-.35	-.37	-.26	-.16	-.25	-.25	-.21	-.15	.29	-.01	.17	.00	-.11	-.12	.08	-.55
TR_E_D	-.32	.32	.35	.25	.22	.33	.30	.26	.21	-.32	.20	-.20	.01	.13	.14	-.09	.64
EUTROPHIC_D	-.25	.29	.32	.24	.22	.31	.28	.24	.20	-.26	.11	-.24	.00	.14	.14	-.06	.63
PC_MT_D	.46	.36	.41	.49	.41	.40	.35	.39	.42	-.13	-.30	-.21	.36	.37	.36	-.26	.09
PC_LT_D	.33	.33	.42	.26	.30	.32	.45	.51	.37	-.63	-.26	.00	.28	.39	.33	-.42	-.03
PC_SN_D	-.42	-.36	-.45	-.36	-.37	-.46	-.54	-.60	-.54	.48	.16	.09	-.26	-.41	-.40	.39	-.05
PT_VT_D	.54	.39	.41	.48	.44	.40	.35	.36	.40	-.08	-.43	-.23	.48	.45	.44	-.40	.02
PT_LA_D	-.34	-.20	-.30	-.21	-.21	-.26	-.33	-.38	-.32	.45	.13	-.09	-.19	-.29	-.24	.29	-.05
SL_FB_D	-.14	-.55	-.60	-.45	-.46	-.59	-.62	-.61	-.52	.67	.14	.32	-.46	-.61	-.60	.60	-.34
SL_BF_D	.06	.59	.64	.49	.50	.61	.66	.65	.56	-.70	-.03	-.28	.45	.60	.59	-.59	.38
SL_HB_D	.09	.57	.62	.46	.47	.60	.65	.65	.54	-.72	-.08	-.27	.45	.60	.59	-.57	.39
PH_CN_D	.57	.16	.18	.22	.08	-.01	.01	.04	.07	.12	-.56	-.09	.23	.20	.22	-.18	-.23
PH_LP_D	-.61	-.24	-.27	-.31	-.20	-.13	-.14	-.18	-.20	-.04	.40	.14	-.37	-.35	-.38	.29	.11
BS_BE_D	-.57	-.09	-.08	-.12	-.15	.15	.13	.04	.08	-.21	.58	-.25	-.12	-.04	.00	-.07	.02
MS_OW_D	.27	-.37	-.38	-.21	-.18	-.33	-.46	-.43	-.35	.33	-.14	.40	-.30	-.44	-.44	.47	-.18
OT_FH_D	-.37	-.50	-.58	-.49	-.47	-.61	-.63	-.68	-.63	.60	.11	.16	-.52	-.64	-.64	.57	-.16

Appendix 5-1. Spearman rank correlations between metrics computed from benthic-macroinvertebrate assemblages and selected land use/land cover, latitude, and area metrics for 30 sites in the Milwaukee to Green Bay, Wis., study area.

[n = 30; significant rho values are noted for p ≤ 0.001, rho = 0.580 (dark green); for p ≤ 0.01, rho = 0.467 (green); and for p ≤ 0.05, rho = 0.362 (light green). Metric definitions are listed in appendix 1.]

Metric abbreviation	iDCA Axis 1	iDCA Axis 2	iDCA Axis 3	iDCA Axis 4	RICH_qq	RICH	RichTOL	ABUND	ABUNDTOL	BIVAL	CHp	CHR	COLEOPp
Land use/land cover, latitude, and area													
UII	0.26	0.28	0.01	0.42	-0.48	-0.47	0.34	-0.40	0.21	-0.18	-0.19	-0.29	-0.35
POPDEN00	.24	.27	-.03	.41	-.49	-.47	.33	-.38	.16	-.24	-.20	-.30	-.35
NLCD_BIS	.36	.23	-.03	.36	-.48	-.39	.43	-.34	.25	-.11	-.16	-.26	-.41
NLCD_IS	.31	.21	.00	.39	-.51	-.42	.40	-.38	.20	-.19	-.14	-.23	-.39
RDLENGTH	.11	-.03	.08	.49	-.40	-.41	.14	-.42	-.02	-.38	-.01	-.19	-.29
P_NLCD1_2	.25	.21	-.02	.41	-.48	-.41	.34	-.40	.19	-.20	-.15	-.23	-.34
P_NLCD1_B2	.21	.25	-.09	.37	-.38	-.35	.32	-.32	.19	-.15	-.18	-.26	-.32
PNLCD_21	.03	.25	-.07	.25	-.32	-.37	.16	-.28	-.01	-.15	-.22	-.27	-.19
PNLCD_21 ÷ P_NLCD1_2	-.58	-.05	-.13	-.36	.55	.34	-.54	.23	-.37	.12	-.02	.08	.50
PNLCD_22	.18	.22	-.05	.41	-.38	-.34	.28	-.37	.16	-.20	-.16	-.18	-.30
PNLCD_23	.33	.23	-.05	.33	-.52	-.42	.40	-.36	.20	-.22	-.19	-.24	-.37
PNLCD_24	.34	.19	.07	.42	-.52	-.44	.38	-.39	.21	-.10	-.13	-.24	-.40
pwNLCD_22	.22	.23	.02	.40	-.43	-.45	.32	-.36	.18	-.17	-.17	-.27	-.30
pwNLCD_23	.35	.25	-.03	.26	-.48	-.43	.42	-.35	.21	-.18	-.20	-.31	-.42
pwNLCD_24	.40	.16	.16	.43	-.51	-.48	.43	-.39	.26	-.07	-.11	-.31	-.49
EDCV_NU	.27	.34	-.01	.52	-.44	-.49	.27	-.43	.29	-.24	-.21	-.29	-.25
P_NLCD1_4	-.54	-.10	.13	.03	.41	.04	-.56	.16	-.39	.07	-.13	-.15	.47
P_NLCD1_B4	-.49	-.09	.08	-.03	.31	.06	-.46	-.01	-.36	-.19	-.09	.00	.37
NP_C4	-.46	.06	.17	.15	.33	-.02	-.57	.06	-.47	-.02	-.10	-.02	.49
PD_C4	-.56	.12	.16	.27	.40	.09	-.60	-.08	-.44	.12	-.12	.02	.53
EDM_C4	.61	-.02	-.15	-.16	-.41	-.02	.62	-.04	.44	-.10	.13	.11	-.50
P_NLCD1_B7	-.43	.12	-.20	-.20	.45	.13	-.52	.04	-.44	.27	-.38	-.19	.50
P_NLCD1_8	-.04	-.07	-.11	-.46	.34	.39	-.18	.22	-.04	.25	.04	.24	.27
P_NLCD1_B9	-.66	.05	.12	.11	.46	.14	-.68	.10	-.54	.12	-.07	-.03	.58
LATITUDE	-.14	-.16	-.33	-.69	.30	.27	-.20	.27	-.09	.07	-.12	-.04	.19

Appendix 5-1. Spearman rank correlations between metrics computed from benthic-macroinvertebrate assemblages and selected land use/land cover, latitude, and area metrics for 30 study sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[n = 30; significant rho values are noted for p ≤ 0.001, rho = 0.580 (dark green); for p ≤ 0.01, rho = 0.467 (green); and for p ≤ 0.05, rho = 0.362 (light green). Metric definitions are listed in appendix 1.]

Metric abbreviation	COLEOPR	DIP	DIPRp	EPEM	EPEMp	EPEMR	EPT	EPTp	EPTRp	EPT_CHRp	GASTRORp	ISOPRp	MOLCRU
Land use/land cover, latitude, and area													
UII	-0.68	-0.34	-0.09	-0.06	0.28	-0.32	-0.26	0.13	-0.12	-0.08	0.04	0.52	-0.18
POPDEN00	-.67	-.31	-.12	-.02	.31	-.28	-.22	.16	-.09	-.05	.05	.56	-.17
NLCD_BIS	-.59	-.28	-.08	-.10	.19	-.33	-.26	.07	-.22	-.11	.17	.46	-.12
NLCD_IS	-.66	-.28	-.03	-.09	.23	-.33	-.25	.11	-.18	-.14	.15	.49	-.20
RDLENGTH	-.59	-.20	-.04	.14	.44	-.06	-.14	.30	.17	.07	.21	.51	-.42
P_NLCD1_2	-.63	-.30	-.05	-.02	.31	-.31	-.26	.10	-.15	-.12	.10	.48	-.19
P_NLCD1_B2	-.57	-.29	-.14	.03	.30	-.24	-.22	.09	-.13	-.05	.06	.43	-.09
PNLCD_21	-.59	-.29	-.18	.15	.41	-.21	-.06	.26	.00	.03	-.03	.42	-.18
PNLCD_21 ÷ P_NLCD1_2	.48	.11	-.14	.31	.15	.32	.27	.12	.25	.25	-.38	-.36	.14
PNLCD_22	-.59	-.30	-.05	.06	.35	-.22	-.22	.11	-.09	-.11	.05	.40	-.21
PNLCD_23	-.63	-.30	-.03	-.12	.21	-.30	-.24	.11	-.18	-.13	.14	.48	-.18
PNLCD_24	-.68	-.29	-.03	-.13	.17	-.35	-.27	.09	-.17	-.13	.17	.50	-.22
pwNLCD_22	-.62	-.31	-.08	-.06	.27	-.31	-.26	.09	-.13	-.08	.05	.49	-.16
pwNLCD_23	-.59	-.30	-.09	-.21	.12	-.33	-.26	.09	-.20	-.08	.11	.49	-.12
pwNLCD_24	-.69	-.25	-.06	-.21	.09	-.41	-.33	.03	-.19	-.10	.22	.56	-.18
EDCV_NU	-.64	-.37	-.12	-.06	.28	-.26	-.36	-.02	-.09	-.07	-.03	.59	-.06
P_NLCD1_4	.30	.01	-.23	.33	.14	.44	.28	.26	.47	.44	-.36	-.06	-.01
P_NLCD1_B4	.21	-.05	-.06	.29	.24	.40	.18	.31	.40	.27	-.34	-.01	-.11
NP_C4	.12	-.04	-.15	.47	.35	.50	.33	.45	.60	.40	-.35	.00	-.38
PD_C4	.15	-.13	-.16	.44	.39	.51	.20	.39	.48	.31	-.54	-.08	-.32
EDM_C4	-.15	.08	.27	-.44	-.34	-.46	-.28	-.37	-.56	-.45	.46	.04	.19
P_NLCD1_B7	.21	-.28	-.37	.14	-.01	.42	.31	.43	.48	.50	-.32	-.23	-.13
P_NLCD1_8	.65	.15	.12	-.14	-.37	.17	.11	-.14	-.04	-.03	-.09	-.47	.15
P_NLCD1_B9	.31	-.01	-.29	.53	.39	.57	.37	.38	.59	.48	-.49	-.17	-.18
LATITUDE	.51	.09	-.16	-.04	-.22	.16	.23	-.07	.10	.23	.12	-.26	.41

Appendix 5-1. Spearman rank correlations between metrics computed from benthic-macroinvertebrate assemblages and selected land use/land cover, latitude, and area metrics for 30 study sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[n = 30; significant rho values are noted for p ≤ 0.001, rho = 0.580 (dark green); for p ≤ 0.01, rho = 0.467 (green); and for p ≤ 0.05, rho = 0.362 (light green). Metric definitions are listed in appendix 1.]

Metric abbreviation	MOLCRUR	NCHDIPR	NONINSR	NONINSRp	NONINSRp_qq	ODIPNIR	OLIGO	TANY	TANYp	TRICH	TRICHR	TRICHRp	FC_abund
Land use/land cover, latitude, and area													
UII	-0.05	-0.44	0.15	0.42	0.50	-0.12	-0.02	-0.28	-0.17	-0.27	-0.24	-0.06	-0.27
POPDEN00	-.05	-.45	.13	.43	.50	-.14	-.05	-.27	-.16	-.24	-.23	-.04	-.24
NLCD_BIS	.07	-.43	.23	.49	.50	-.05	.04	-.22	-.11	-.28	-.29	-.14	-.28
NLCD_IS	.00	-.44	.18	.45	.50	-.10	.01	-.23	-.13	-.25	-.27	-.09	-.26
RDLENGTH	-.16	-.37	-.16	.20	.32	-.34	-.09	-.03	.10	-.26	-.07	.16	-.25
P_NLCD1_2	-.02	-.41	.16	.41	.48	-.10	-.04	-.23	-.12	-.27	-.23	-.06	-.27
P_NLCD1_B2	.00	-.40	.21	.46	.45	-.06	-.08	-.19	-.10	-.25	-.20	-.07	-.24
PNLCD_21	-.07	-.29	.11	.37	.41	-.10	-.10	-.20	-.14	-.10	-.07	.07	-.08
PNLCD_21 ÷ P_NLCD1_2	-.10	.59	-.19	-.34	-.43	.12	-.24	.06	-.01	.25	.36	.20	.30
PNLCD_22	-.05	-.40	.15	.35	.41	-.10	-.09	-.17	-.08	-.25	-.16	-.02	-.25
PNLCD_23	-.03	-.43	.14	.42	.44	-.13	-.01	-.26	-.17	-.24	-.30	-.12	-.24
PNLCD_24	.04	-.48	.19	.46	.54	-.09	.06	-.24	-.14	-.28	-.26	-.08	-.28
pwNLCD_22	-.06	-.45	.16	.43	.53	-.10	-.05	-.25	-.15	-.25	-.21	-.05	-.27
pwNLCD_23	.00	-.38	.19	.48	.51	-.04	.06	-.32	-.23	-.22	-.28	-.13	-.23
pwNLCD_24	.11	-.47	.27	.54	.63	-.01	.13	-.27	-.16	-.31	-.25	-.08	-.31
EDCV_NU	-.08	-.47	.13	.43	.50	-.13	-.12	-.34	-.23	-.38	-.26	-.08	-.40
P_NLCD1_4	-.12	.19	-.33	-.33	-.24	-.16	-.21	.02	-.04	.20	.32	.31	.21
P_NLCD1_B4	-.23	.30	-.45	-.43	-.31	-.26	-.30	-.02	-.04	.09	.27	.26	.08
NP_C4	-.34	-.03	-.46	-.45	-.38	-.42	-.27	.00	-.06	.18	.33	.41	.20
PD_C4	-.21	.08	-.27	-.40	-.29	-.20	-.28	-.12	-.15	.09	.32	.28	.13
EDM_C4	.19	-.10	.28	.33	.20	.18	.26	.05	.08	-.18	-.41	-.40	-.20
P_NLCD1_B7	-.04	.16	-.13	-.25	-.31	-.10	-.31	-.17	-.29	.38	.37	.37	.36
P_NLCD1_8	.02	.39	-.12	-.43	-.51	.08	.05	.05	-.04	.19	.04	-.09	.17
P_NLCD1_B9	-.20	.17	-.30	-.39	-.29	-.13	-.25	-.07	-.12	.24	.45	.39	.26
LATITUDE	.18	.54	-.03	-.11	-.27	.24	-.06	.10	.02	.30	.14	.07	.25

Appendix 5-1. Spearman rank correlations between metrics computed from benthic-macroinvertebrate assemblages and selected land use/land cover, latitude, and area metrics for 30 study sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[n = 30; significant rho values are noted for p ≤ 0.001, rho = 0.580 (dark green); for p ≤ 0.01, rho = 0.467 (green); and for p ≤ 0.05, rho = 0.362 (light green). Metric definitions are listed in appendix 1.]

Metric abbreviation	pFC_rich	GC_rich	pGC_rich	pOM_rich	PR_rich	SC_abund	SC_rich	SH_rich	Margalef
Land use/land cover, latitude, and area									
UII	0.35	-0.47	-0.21	0.10	-0.16	-0.58	-0.47	-0.48	-0.26
POPDEN00	.31	-.47	-.22	.11	-.16	-.58	-.48	-.44	-.27
NLCD_BIS	.20	-.37	-.12	.05	-.14	-.53	-.40	-.38	-.20
NLCD_IS	.30	-.40	-.14	.06	-.22	-.57	-.42	-.40	-.21
RDLENGTH	.39	-.38	-.16	.03	-.43	-.40	-.17	-.23	-.18
P_NLCD1_2	.35	-.42	-.19	.06	-.18	-.54	-.42	-.41	-.20
P_NLCD1_B2	.26	-.41	-.24	.09	-.08	-.43	-.38	-.34	-.19
PNLCD_21	.38	-.48	-.34	.18	-.10	-.42	-.40	-.34	-.23
PNLCD_21 ÷ P_NLCD1_2	-.02	.13	-.22	.09	.42	.42	.19	.24	.19
PNLCD_22	.36	-.40	-.24	.11	-.18	-.45	-.36	-.33	-.16
PNLCD_23	.24	-.39	-.11	.06	-.21	-.57	-.42	-.36	-.22
PNLCD_24	.33	-.40	-.11	.07	-.27	-.60	-.41	-.45	-.22
pwNLCD_22	.36	-.46	-.23	.10	-.16	-.52	-.45	-.43	-.25
pwNLCD_23	.14	-.36	-.08	.02	-.10	-.61	-.41	-.46	-.23
pwNLCD_24	.26	-.36	-.02	.01	-.29	-.64	-.38	-.53	-.26
EDCV_NU	.32	-.45	-.17	.09	-.10	-.56	-.51	-.49	-.28
P_NLCD1_4	.09	-.18	-.42	.37	.16	.24	.06	.06	-.06
P_NLCD1_B4	.04	-.12	-.32	.26	.15	.16	-.01	.20	.03
NP_C4	.37	-.19	-.37	.39	-.23	.06	.05	.15	-.07
PD_C4	.39	-.19	-.52	.57	.10	-.09	-.11	-.08	.07
EDM_C4	-.33	.23	.51	-.47	-.09	-.08	.02	.06	.03
P_NLCD1_B7	.08	-.05	-.28	.45	-.08	.10	.20	.04	.06
P_NLCD1_8	-.37	.45	.28	-.11	.12	.36	.35	.35	.21
P_NLCD1_B9	.31	-.12	-.46	.44	.16	.08	.02	-.03	.07
LATITUDE	-.44	.30	.20	-.22	.25	.52	.38	.36	.13

Appendix 5-2. Spearman rank correlations between metrics computed from benthic-macroinvertebrate assemblages and selected habitat and hydrologic metrics for 30 study sites in the Milwaukee to Green Bay, Wis., study area.

[Except for pre-ice and post-ice hydrologic-condition metrics; n = 30, for p ≤ 0.001 rho = 0.580 (dark green), for p ≤ 0.01 rho = 0.467 (green), for p ≤ 0.05 rho = 0.362 (light green). Pre-ice hydrologic-condition metrics are area based; n = 22; for p ≤ 0.001 rho = 0.667 (dark green), for p ≤ 0.01 rho = 0.544 (green), for p ≤ 0.05 rho = 0.423 (light green). Post-ice hydrologic-condition metrics are area based; n = 24; p ≤ 0.001 rho = 0.642 (dark green), for p ≤ 0.01 rho = 0.521 (green), for p ≤ 0.05 rho = 0.404 (light green). Metric definitions are listed in appendix 1.]

Metric abbreviation	iDCA Axis 1	iDCA Axis 2	iDCA Axis 3	iDCA Axis 4	RICH_qq	RICH	RichTOL	ABUND	ABUNDTOL	BIVAL	CHp	CHR	COLEOPp
Habitat													
BFWidthDepthAvg	-0.14	-0.05	0.28	0.41	-0.02	-0.31	-0.16	-0.01	-0.17	-0.13	0.06	-0.19	0.13
GCUTypeRiffPct	-.42	.01	-.02	.00	-.01	-.01	-.34	-.27	-.39	-.46	-.15	-.06	.28
GCUTypePoolPct	-.44	-.15	-.12	.00	.51	.35	-.43	.19	-.23	-.01	.10	.18	.23
GCUTypeRunPct	.59	.07	.09	-.01	-.42	-.25	.54	-.02	.40	.27	.04	-.10	-.36
Froude	-.24	.16	.03	-.05	-.01	-.21	-.18	-.18	-.20	-.03	-.24	-.32	.19
BedSubStab	-.37	-.01	.15	-.15	.05	.09	-.27	.12	-.35	-.10	-.04	.02	.42
BankVegCovPct	-.17	-.10	.15	-.34	.17	.14	-.22	.72	-.21	.14	.19	-.10	.10
ErosionLengthAvg	.27	.36	.03	.51	-.37	-.48	.21	-.59	.28	-.13	-.27	-.28	-.17
Hydrology, pre-ice period (Oct. 1 to Dec. 8, 2003)													
pct_25n	.16	-.47	.14	.27	.21	.40	.17	.10	.32	.01	.49	.44	-.47
pct_5n	.07	-.44	.09	.19	.30	.52	.05	.25	.22	.13	.57	.49	-.29
day_pctchange	.49	.02	-.09	.10	-.65	-.48	.55	-.36	.32	-.20	-.12	-.20	-.52
periodr1	-.05	.17	-.27	-.06	.44	.57	.05	-.08	.03	.37	.07	.29	-.08
MDH_95	.04	-.25	.11	-.09	.24	.33	-.10	.32	.10	-.09	.46	.55	.03
MXL_25	-.06	.29	-.20	.03	-.08	-.20	-.17	-.40	-.02	-.05	-.43	-.21	.29
Hydrology, post-ice period (Mar. 16 to Oct. 30, 2004)													
pct_99n	.32	-.05	.30	.29	-.39	-.46	.34	-.10	.43	-.41	.25	.12	-.24
day_pctchange	.40	-.10	.36	.21	-.46	-.43	.46	-.06	.42	-.27	.24	-.01	-.40
rb_flash	.36	-.12	.32	.23	-.48	-.45	.42	-.08	.42	-.35	.21	.05	-.33
periodr1	-.41	-.32	-.33	-.14	.61	.62	-.26	-.08	-.15	.21	.21	.42	.20
periodr9	.34	.07	.33	.51	-.39	-.37	.31	-.29	.22	-.16	.11	-.07	-.39
periodf1	-.25	-.40	-.36	-.05	.45	.65	-.18	-.25	-.12	.34	.27	.42	-.07
MXH_95	-.37	.42	-.10	.33	.20	-.10	-.45	-.37	-.24	-.27	-.17	.07	.45
MXL_5	-.48	.11	-.27	.07	.35	.47	-.45	-.39	-.39	.03	-.11	.22	.40
Hydrology (annual streamflow)													
Q10	-.09	-.06	.28	.23	-.06	-.24	-.15	-.02	-.20	-.12	.10	.02	.19
Q50	-.28	.26	.03	.30	-.10	-.39	-.28	-.05	-.44	-.10	-.28	-.35	.28
Q90	-.33	.17	.32	.24	.03	-.28	-.33	.16	-.50	-.11	-.13	-.38	.15
Qmax_instDA	.29	.05	-.08	.48	-.39	-.25	.30	-.38	.28	-.51	.00	.08	-.21
Q_50DA	-.14	.36	.05	.46	-.31	-.44	-.04	-.18	-.28	-.17	-.26	-.38	.08
Q_bnkflDA	.08	.08	.16	.15	-.54	-.32	.18	-.02	.01	-.28	-.05	-.11	-.07
INSTDIS - spring	-.49	-.04	.20	.43	.06	-.07	-.51	-.10	-.49	-.05	-.04	-.11	.26
INSTDIS - summer	-.24	.05	.16	.12	-.02	-.13	-.20	.09	-.39	-.08	-.06	-.21	.13

Appendix 5-2. Spearman rank correlations between metrics computed from benthic-macroinvertebrate assemblages and selected habitat and hydrologic metrics for 30 study sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[Except for pre-ice and post-ice hydrologic-condition metrics; n = 30, for p ≤ 0.001 rho = 0.580 (dark green), for p ≤ 0.01 rho = 0.467 (green), for p ≤ 0.05 rho = 0.362 (light green). Pre-ice hydrologic-condition metrics are area based; n = 22; for p ≤ 0.001 rho = 0.667 (dark green), for p ≤ 0.01 rho = 0.544 (green), for p ≤ 0.05 rho = 0.423 (light green). Post-ice hydrologic-condition metrics are area based; n = 24; p ≤ 0.001 rho = 0.642 (dark green), for p ≤ 0.01 rho = 0.521 (green), for p ≤ 0.05 rho = 0.404 (light green). Metric definitions are listed in appendix 1.]

Metric abbreviation	COLEOPR	DIP	DIPRp	EPEM	EPEMp	EPEMR	EPT	EPTp	EPTRp	EPT_CHRp	GASTRORp	ISOPRp	MOLCRU
Habitat													
BFWidthDepthAvg	-0.38	-0.04	-0.15	0.19	0.24	0.02	0.09	0.22	0.32	0.26	0.11	0.26	-0.23
GCUTypeRiffPct	-.15	-.33	-.14	.13	.41	.09	.05	.37	.34	.28	-.02	.01	-.49
GCUTypePoolPct	.19	.09	-.16	.56	.39	.27	.33	.09	.41	.29	.00	-.39	.02
GCUTypeRunPct	-.07	.11	.18	-.51	-.54	-.25	-.27	-.25	-.51	-.38	.08	.24	.23
Froude	-.27	-.30	-.32	.05	.20	-.16	.06	.23	.19	.30	-.08	.20	-.19
BedSubStab	.01	-.02	-.15	-.04	-.08	.08	.30	.19	.21	.19	-.06	-.17	-.15
BankVegCovPct	.21	.58	-.32	.20	-.25	.22	.57	-.02	.24	.30	.04	-.13	.37
ErosionLengthAvg	-.37	-.55	-.01	-.09	.32	-.30	-.50	-.03	-.08	-.05	-.17	.45	-.23
Hydrology, pre-ice period (Oct. 1 to Dec. 8, 2003)													
pct_25n	.06	.32	.30	.16	-.07	.06	-.02	-.38	-.12	-.27	.37	-.35	.14
pct_5n	.15	.54	.23	.32	-.08	.31	.11	-.29	-.13	-.29	.28	-.42	.21
day_pctchange	-.69	-.22	.08	-.35	.10	-.64	-.21	-.02	-.36	-.18	.55	.59	-.01
periodr1	.31	-.06	-.01	-.04	-.05	.26	-.06	.05	-.14	-.03	-.15	-.60	.04
MDH_95	.31	.47	.45	.21	-.14	.15	.07	-.34	-.01	-.37	.06	-.27	.08
MXL_25	.01	-.69	-.18	-.14	.09	-.08	-.22	.13	.30	.28	-.15	.06	-.19
Hydrology, post-ice period (Mar. 16 to Oct. 30, 2004)													
pct_99n	-.41	.10	.46	-.18	-.01	-.65	-.41	-.38	-.36	-.46	.12	.51	.01
day_pctchange	-.55	.16	.32	-.41	-.19	-.73	-.34	-.35	-.46	-.41	.26	.56	.08
rb_flash	-.49	.10	.42	-.36	-.15	-.72	-.38	-.37	-.45	-.46	.20	.53	.04
periodr1	.34	.02	.07	.09	.09	.22	-.01	-.01	-.03	-.02	.03	-.64	.04
periodr9	-.59	-.10	.05	.03	.16	-.18	-.21	.07	-.11	-.19	.14	.44	-.24
periodf1	.38	-.06	.01	.24	.20	.39	-.01	.14	.09	.04	.14	-.66	-.13
MXH_95	.16	-.39	.01	.40	.56	.35	-.20	.27	.30	.08	-.63	.02	-.43
MXL_5	.57	-.30	-.12	.27	.37	.75	-.01	.36	.27	.20	-.50	-.40	-.31
Hydrology (annual streamflow)													
Q10	-.21	.05	.05	.14	.12	.16	.11	.24	.32	.10	-.01	.21	-.28
Q50	-.39	-.21	-.41	.36	.38	.31	.35	.64	.54	.51	-.25	.36	-.34
Q90	-.32	-.04	-.48	.45	.35	.25	.50	.58	.60	.62	-.15	.23	-.35
Qmax_instDA	-.41	-.25	.30	-.26	.05	-.17	-.53	-.21	-.24	-.32	.05	.29	-.13
Q_50DA	-.59	-.23	-.37	.14	.29	.11	.10	.47	.21	.27	-.31	.45	-.23
Q_bnkflDA	-.54	-.08	.00	-.21	-.12	-.31	-.05	-.02	-.13	-.13	.07	.31	-.07
INSTDIS - spring	-.08	-.13	-.28	.49	.41	.51	.25	.48	.66	.47	-.32	-.01	-.50
INSTDIS - summer	-.33	-.03	-.38	.30	.25	.19	.48	.49	.50	.48	.06	.13	-.32

Appendix 5-2. Spearman rank correlations between metrics computed from benthic-macroinvertebrate assemblages and selected habitat and hydrologic metrics for 30 study sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[Except for pre-ice and post-ice hydrologic-condition metrics; n = 30, for p ≤ 0.001 rho = 0.580 (dark green), for p ≤ 0.01 rho = 0.467 (green), for p ≤ 0.05 rho = 0.362 (light green). Pre-ice hydrologic-condition metrics are area based; n = 22; for p ≤ 0.001 rho = 0.667 (dark green), for p ≤ 0.01 rho = 0.544 (green), for p ≤ 0.05 rho = 0.423 (light green). Post-ice hydrologic-condition metrics are area based; n = 24; p ≤ 0.001 rho = 0.642 (dark green), for p ≤ 0.01 rho = 0.521 (green), for p ≤ 0.05 rho = 0.404 (light green). Metric definitions are listed in appendix 1.]

Metric abbreviation	MOLCRUR	NCHDIPR	NONINSR	NONINSRp	NONINSRp_qq	ODIPNIR	OLIGO	TANY	TANYp	TRICH	TRICHR	TRICHRp	FC_abund
Habitat													
BFWidthDepthAvg	-0.06	-0.40	-0.11	0.07	0.17	-0.31	-0.30	0.04	0.09	-0.01	0.23	0.37	-0.03
GCUTypeRiffPct	-.21	.02	-.21	-.18	-.16	-.23	-.46	-.13	-.06	.03	.38	.44	-.06
GCUTypePoolPct	-.02	.20	-.02	-.18	-.16	.14	-.14	.28	.25	.25	.58	.53	.24
GCUTypeRunPct	.17	-.16	.18	.24	.23	.08	.42	-.08	-.10	-.17	-.66	-.64	-.14
Froude	-.05	.07	.08	.22	.20	.08	-.32	-.34	-.33	.11	.27	.35	.07
BedSubStab	.06	-.10	.05	-.15	-.12	-.05	-.12	-.03	-.10	.36	.33	.27	.29
BankVegCovPct	.17	.06	.13	.06	-.18	.19	.24	.39	.22	.58	.21	.19	.58
ErosionLengthAvg	-.35	-.25	-.17	.17	.34	-.26	-.16	-.64	-.50	-.55	-.22	-.02	-.55
Hydrology, pre-ice period (Oct. 1 to Dec. 8, 2003)													
pct_25n	.23	.10	.27	.04	.08	.42	.39	.53	.62	-.05	.12	-.06	-.05
pct_5n	.32	.11	.36	.03	-.06	.49	.32	.69	.68	.07	.01	-.26	.11
day_pctchange	.22	-.47	.20	.49	.60	-.06	.11	-.33	-.19	-.18	-.33	-.10	-.18
periodr1	.22	.34	.29	-.03	-.13	.41	.09	.02	.07	-.02	.12	-.22	.05
MDH_95	-.12	.28	-.23	-.40	-.46	-.04	.13	.61	.57	-.09	.04	-.10	-.04
MXL_25	-.26	.08	-.32	-.21	-.11	-.36	-.17	-.54	-.45	-.22	.20	.41	-.29
Hydrology, post-ice period (Mar. 16 to Oct. 30, 2004)													
pct_99n	-.34	-.33	-.30	.10	.26	-.37	.10	-.01	.11	-.46	-.28	-.12	-.44
day_pctchange	-.03	-.27	.02	.36	.45	-.08	.33	-.08	.04	-.30	-.28	-.15	-.26
rb_flash	-.16	-.25	-.14	.22	.34	-.21	.25	-.06	.06	-.38	-.31	-.16	-.34
periodr1	.26	.41	.27	-.19	-.12	.39	-.15	.25	.27	.14	.33	.05	.16
periodr9	-.07	-.43	.09	.30	.38	-.11	.25	-.13	-.05	-.24	-.22	-.06	-.21
periodf1	.27	.42	.27	-.20	-.11	.38	.01	.31	.40	.06	.28	.05	.07
MXH_95	-.71	-.10	-.62	-.49	-.39	-.59	-.62	-.22	-.22	-.31	.01	.05	-.32
MXL_5	-.13	.47	-.17	-.53	-.52	.01	-.40	-.18	-.15	-.01	.09	-.07	-.05
Hydrology (annual streamflow)													
Q10	-.26	-.36	-.34	-.23	-.07	-.52	-.18	.00	-.01	.03	.09	.23	.02
Q50	-.22	-.39	-.26	.02	.08	-.43	-.27	-.20	-.21	.24	.13	.34	.23
Q90	-.12	-.28	-.11	.09	.11	-.20	-.15	-.11	-.13	.35	.44	.55	.33
Qmax_instDA	-.22	-.41	-.11	.11	.19	-.31	-.18	-.14	-.01	-.52	-.35	-.28	-.54
Q_50DA	-.09	-.49	.01	.31	.37	-.24	-.16	-.32	-.30	.06	-.09	.03	.06
Q_bnkflDA	.06	-.28	.12	.29	.30	-.05	.02	-.06	-.05	-.02	-.13	-.06	-.09
INSTDIS - spring	-.22	-.17	-.26	-.26	-.10	-.28	-.22	-.02	.02	.10	.41	.45	.07
INSTDIS - summer	.06	-.16	.07	.10	.08	.00	-.09	-.03	-.03	.44	.42	.54	.39

Appendix 5-2. Spearman rank correlations between metrics computed from benthic-macroinvertebrate assemblages and selected habitat and hydrologic metrics for 30 study sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[Except for pre-ice and post-ice hydrologic-condition metrics; n = 30, for p ≤ 0.001 rho = 0.580 (dark green), for p ≤ 0.01 rho = 0.467 (green), for p ≤ 0.05 rho = 0.362 (light green). Pre-ice hydrologic-condition metrics are area based; n = 22; for p ≤ 0.001 rho = 0.667 (dark green), for p ≤ 0.01 rho = 0.544 (green), for p ≤ 0.05 rho = 0.423 (light green). Post-ice hydrologic-condition metrics are area based; n = 24; p ≤ 0.001 rho = 0.642 (dark green), for p ≤ 0.01 rho = 0.521 (green), for p ≤ 0.05 rho = 0.404 (light green). Metric definitions are listed in appendix 1.]

Metric abbreviation	pFC_rich	GC_rich	pGC_rich	pOM_rich	PR_rich	SC_abund	SC_rich	SH_rich	Margalef
Habitat									
BFWidthDepthAvg	0.50	-0.33	-0.19	0.12	-0.47	0.02	-0.02	-0.16	-0.23
GCUTypeRiffPct	.44	-.02	-.10	-.08	-.15	-.02	.19	-.17	.13
GCUTypePoolPct	.35	.12	-.25	.07	.16	.42	.39	.09	.29
GCUTypeRunPct	-.54	-.05	.25	-.04	-.05	-.28	-.30	-.03	-.27
Froude	.48	-.15	-.06	.04	-.18	-.19	-.09	-.30	-.14
BedSubStab	.21	.08	-.01	.01	-.08	.03	.14	-.20	.08
BankVegCovPct	-.26	.04	-.06	-.13	.10	.49	.38	.31	-.17
ErosionLengthAvg	.50	-.35	-.04	.01	-.16	-.67	-.52	-.55	-.21
Hydrology, pre-ice period (Oct. 1 to Dec. 8, 2003)									
pct_25n	-.06	.42	.10	-.19	.31	.22	.38	.11	.44
pct_5n	-.23	.37	-.07	-.01	.38	.38	.45	.28	.44
day_pctchange	.14	-.23	.29	-.11	-.32	-.56	-.50	-.39	-.26
periodr1	-.18	.59	.21	.07	.43	-.08	.15	-.07	.62
MDH_95	-.26	.46	.33	-.34	.00	.59	.36	.67	.17
MXL_25	.17	-.02	.14	-.11	-.15	-.21	-.02	-.29	.00
Hydrology, post-ice period (Mar. 16 to Oct. 30, 2004)									
pct_99n	.30	-.26	.16	-.35	-.13	-.17	-.39	-.10	-.36
day_pctchange	.14	-.19	.24	-.31	-.03	-.37	-.41	-.30	-.33
rb_flash	.15	-.22	.21	-.32	-.04	-.28	-.41	-.21	-.34
periodr1	.00	.49	.00	.08	.36	.30	.42	.01	.63
periodr9	.29	-.40	-.24	.08	-.15	-.58	-.31	-.38	-.16
periodf1	-.09	.50	-.06	.05	.29	.19	.54	.13	.72
MXH_95	.59	-.38	-.56	.19	.00	-.10	-.18	.01	.00
MXL_5	-.03	.22	-.33	.32	.40	-.10	.09	.14	.53
Hydrology (annual streamflow)									
Q10	.36	-.24	-.08	.07	-.61	-.06	-.02	.11	-.22
Q50	.34	-.48	-.41	.58	-.32	-.28	-.31	-.19	-.36
Q90	.38	-.34	-.36	.38	-.29	-.16	-.08	-.23	-.29
Qmax_instDA	-.07	-.12	.10	-.06	-.06	-.25	-.25	-.15	-.06
Q_50DA	.20	-.53	-.42	.57	-.07	-.54	-.54	-.52	-.36
Q_bnkflDA	.01	-.17	.10	-.01	-.15	-.17	-.28	-.20	-.26
INSTDIS - spring	.28	-.18	-.37	.46	-.23	-.02	.10	-.09	-.06
INSTDIS - summer	.37	-.08	-.08	.26	-.41	-.16	.02	-.10	-.12

Appendix 5-3. Spearman rank correlations between metrics computed from benthic-macroinvertebrate assemblages and selected chemistry metrics for 30 study sites in the Milwaukee to Green Bay, Wis., study area.

[SPMD, semipermeable membrane device. Except for SPMD metrics;, n = 30, for p ≤ 0.001 rho = 0.580 (dark green), for p ≤ 0.01 rho = 0.467 (green), for p ≤ 0.05 rho = 0.362 (light green). SPMD metrics; n = 28, for p ≤ 0.001 rho = 0.598 (dark green), for p ≤ 0.01 rho = 0.483 (green), for p ≤ 0.05 rho = 0.375 (light green). Metric definitions are listed in appendix 1.]

Metric abbreviation	iDCA Axis 1	iDCA Axis 2	iDCA Axis 3	iDCA Axis 4	RICH_qq	RICH	RichTOL	ABUND	ABUNDTOL	BIVAL	CHp	CHR	COLEOPp
Water chemistry, spring													
SPCOND	0.43	-0.04	-0.05	0.00	-0.38	-0.28	0.46	-0.18	0.30	-0.18	-0.02	-0.12	-0.40
CHLOR	.37	.04	-.05	.12	-.45	-.39	.40	-.28	.24	-.22	-.10	-.21	-.39
NITRITE	.32	.11	.00	.21	-.23	-.11	.21	-.15	.27	.48	-.11	-.18	-.19
TPCONC	.14	.05	-.08	-.04	-.16	.06	-.01	-.08	-.12	.09	-.05	.06	-.03
TICONC	.44	.26	.01	.11	-.62	-.64	.37	-.23	.30	-.15	-.35	-.39	-.34
PTI_CLAD	.47	.04	.00	.18	-.64	-.54	.44	-.39	.39	-.28	-.20	-.19	-.39
PTI_INV	.52	.08	.14	.40	-.67	-.57	.45	-.38	.32	-.21	-.08	-.21	-.41
Water chemistry, summer													
SPCOND	.17	.08	.15	.35	-.21	-.22	.14	-.47	.12	-.07	-.08	-.04	-.18
CHLOR	.38	.16	.15	.44	-.36	-.31	.41	-.51	.33	-.04	-.07	-.13	-.35
NITRITE	-.05	-.21	.47	.24	-.14	.18	.05	.13	-.13	-.05	.46	.16	-.27
TPCONC	.57	-.08	.04	-.18	-.36	-.19	.52	.12	.39	.13	.10	-.04	-.23
PTI_CLAD	.51	-.04	.00	.08	-.53	-.38	.53	-.11	.37	-.16	.05	-.11	-.38
PTI_INV	.50	.01	-.03	.21	-.52	-.41	.47	-.07	.36	-.09	-.01	-.14	-.27
PTI_FISH	.51	-.20	-.03	-.20	-.42	-.19	.52	.03	.35	-.08	.14	.03	-.26
SPMD chemistry													
TEQ	.44	.26	.13	.42	-.56	-.52	.50	-.45	.28	.00	-.14	-.35	-.51
UPAH	.23	.29	.12	.40	-.49	-.44	.31	-.49	.08	-.18	-.18	-.31	-.38
S_PCA	.40	.18	.04	.28	-.34	-.23	.51	-.32	.33	-.12	-.03	-.02	-.35
S_FLUOR	.26	.33	.13	.46	-.46	-.48	.34	-.49	.19	-.15	-.23	-.35	-.38
S_PHENA	.22	.35	.12	.43	-.43	-.48	.31	-.49	.18	-.21	-.24	-.34	-.32
S_PYRE	.26	.32	.15	.47	-.45	-.48	.35	-.49	.20	-.17	-.22	-.34	-.38
DETECTS	.43	.19	.25	.49	-.54	-.55	.53	-.32	.35	.02	-.03	-.35	-.53

Appendix 5-3. Spearman rank correlations between metrics computed from benthic-macroinvertebrate assemblages and selected chemistry metrics for 30 study sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[SPMD, semipermeable membrane device. Except for SPMD metric; n = 30, for p ≤ 0.001 rho = 0.580 (dark green), for p ≤ 0.01 rho = 0.467 (green), for p ≤ 0.05 rho = 0.362 (light green). SPMD metrics; n = 28, for p ≤ 0.001 rho = 0.598 (dark green), for p ≤ 0.01 rho = 0.483 (green), for p ≤ 0.05 rho = 0.375 (light green). Metric definitions are listed in appendix 1.]

Metric abbreviation	COLEOPR	DIP	DIPRp	EPEM	EPEMp	EPEMR	EPT	EPTp	EPTRp	EPT_CHRp	GASTRORp	ISOPRp	MOLCRU
Water chemistry, spring													
SPCOND	-0.49	-0.09	0.13	-0.28	-0.04	-0.50	-0.21	-0.10	-0.33	-0.26	0.45	0.35	0.04
CHLOR	-.56	-.20	.07	-.19	.13	-.42	-.22	.04	-.21	-.16	.36	.48	-.09
NITRITE	-.11	-.14	-.17	-.22	-.30	-.05	-.15	-.12	-.09	-.01	-.06	.03	.12
TPCONC	.17	-.07	.05	-.03	-.04	.15	.07	.20	.04	.03	-.03	-.10	-.25
TICONC	-.59	-.38	-.01	-.28	-.06	-.52	-.20	-.01	-.10	-.04	.10	.61	-.03
PTI_CLAD	-.60	-.34	.23	-.41	-.07	-.49	-.41	-.10	-.25	-.24	.26	.61	-.07
PTI_INV	-.67	-.26	.18	-.41	-.11	-.37	-.40	-.02	-.20	-.23	.21	.64	-.17
Water chemistry, summer													
SPCOND	-.36	-.31	.14	-.24	.06	-.28	-.41	-.01	-.09	-.17	.00	.29	-.22
CHLOR	-.45	-.29	.10	-.32	.04	-.35	-.48	-.06	-.28	-.25	.10	.43	-.14
NITRITE	.01	.33	.02	.08	-.07	.12	.15	.07	.08	.07	.08	-.12	-.11
TPCONC	-.16	.24	.22	-.64	-.59	-.31	-.15	-.30	-.43	-.34	.40	.28	.29
PTI_CLAD	-.40	.03	.27	-.61	-.41	-.30	-.33	-.21	-.42	-.39	.22	.47	.13
PTI_INV	-.41	.02	.17	-.46	-.31	-.17	-.23	-.13	-.32	-.28	.21	.49	.14
PTI_FISH	-.19	.19	.34	-.68	-.55	-.34	-.21	-.28	-.44	-.41	.44	.27	.21
SPMD chemistry													
TEQ	-.72	-.33	-.11	-.21	.14	-.36	-.33	.16	-.20	-.11	.08	.60	-.19
UPAH	-.59	-.36	-.14	-.07	.33	-.20	-.24	.27	-.06	-.01	.00	.54	-.29
S_PCA	-.31	-.07	.23	-.40	-.10	-.25	-.36	-.05	-.46	-.38	-.04	.31	-.07
S_FLUOR	-.61	-.40	-.16	-.06	.32	-.26	-.31	.18	-.08	-.01	-.03	.56	-.24
S_PHENA	-.58	-.43	-.15	-.06	.33	-.26	-.32	.17	-.08	-.01	-.06	.56	-.23
S_PYRE	-.61	-.39	-.15	-.07	.32	-.28	-.32	.16	-.09	-.02	-.03	.55	-.24
DETECTS	-.67	-.14	-.12	-.19	.04	-.38	-.31	.00	-.22	-.12	.11	.63	-.04

Appendix 5-3. Spearman rank correlations between metrics computed from benthic-macroinvertebrate assemblages and selected chemistry metrics for 30 study sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[SPMD, semipermeable membrane device. Except for SPMD metric;, n = 30, for p ≤ 0.001 rho = 0.580 (dark green), for p ≤ 0.01 rho = 0.467 (green), for p ≤ 0.05 rho = 0.362 (light green). SPMD metrics; n = 28, for p ≤ 0.001 rho = 0.598 (dark green), for p ≤ 0.01 rho = 0.483 (green), for p ≤ 0.05 rho = 0.375 (light green). Metric definitions are listed in appendix 1.]

Metric abbreviation	MOLCRUR	NCHDIPR	NONINSR	NONINSRp	NONINSRp_qq	ODIPNIR	OLIGO	TANY	TANYp	TRICH	TRICHR	TRICHRp	FC_abund
Water chemistry, spring													
SPCOND	0.15	-0.12	0.19	0.39	0.33	0.05	0.07	-0.04	0.01	-0.12	-0.23	-0.07	-0.12
CHLOR	.02	-.18	.06	.38	.38	-.09	.00	-.12	-.04	-.18	-.25	-.02	-.19
NITRITE	.30	-.12	.38	.20	.27	.29	.41	-.19	-.17	-.05	-.17	-.16	-.06
TPCONC	-.03	.02	-.16	-.23	-.23	-.11	.05	-.19	-.16	.07	-.13	-.09	.05
TICONC	-.09	-.31	-.06	.35	.47	-.19	.05	-.45	-.38	-.19	-.26	.01	-.23
PTI_CLAD	.00	-.23	-.04	.34	.48	-.14	-.01	-.31	-.16	-.39	-.42	-.19	-.43
PTI_INV	.03	-.31	-.01	.30	.43	-.16	.01	-.27	-.12	-.34	-.42	-.19	-.41
Water chemistry, summer													
SPCOND	-.06	-.10	-.12	.06	.25	-.20	.09	-.27	-.17	-.42	-.02	.05	-.40
CHLOR	.06	-.20	.10	.28	.42	-.05	.18	-.28	-.15	-.47	-.29	-.17	-.46
NITRITE	.08	.07	.03	.02	-.04	.14	.38	.20	.24	.05	.25	.13	.07
TPCONC	.33	-.13	.24	.23	.10	.07	.24	.08	.08	.02	-.52	-.43	.02
PTI_CLAD	.06	-.23	.08	.27	.22	-.10	.02	-.03	.04	-.15	-.59	-.48	-.17
PTI_INV	.17	-.39	.13	.28	.25	-.10	.03	.02	.09	-.11	-.63	-.49	-.13
PTI_FISH	.22	-.11	.11	.14	.07	-.03	.14	.13	.15	-.01	-.49	-.40	-.03
SPMD chemistry													
TEQ	.08	-.44	.24	.53	.64	-.02	.17	-.33	-.18	-.35	-.35	-.17	-.35
UPAH	-.05	-.36	.11	.38	.51	-.07	.02	-.41	-.28	-.27	-.22	-.05	-.30
S_PCA	-.03	-.39	.12	.18	.28	-.10	.23	-.18	-.11	-.28	-.56	-.50	-.23
S_FLUOR	-.06	-.46	.13	.41	.56	-.10	.02	-.42	-.30	-.37	-.23	-.05	-.38
S_PHENA	-.14	-.37	.07	.39	.52	-.13	-.06	-.44	-.32	-.37	-.22	-.04	-.40
S_PYRE	-.07	-.45	.13	.42	.56	-.10	.02	-.42	-.30	-.38	-.22	-.05	-.39
DETECTS	.08	-.58	.29	.59	.75	-.02	.27	-.21	-.11	-.33	-.36	-.19	-.33

Appendix 5-3. Spearman rank correlations between metrics computed from benthic-macroinvertebrate assemblages and selected chemistry metrics for 30 study sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[SPMD, semipermeable membrane device. Except for SPMD metrics; n = 30, for p ≤ 0.001 rho = 0.580 (dark green), for p ≤ 0.01 rho = 0.467 (green), for p ≤ 0.05 rho = 0.362 (light green). SPMD metrics; n = 28, for p ≤ 0.001 rho = 0.598 (dark green), for p ≤ 0.01 rho = 0.483 (green), for p ≤ 0.05 rho = 0.375 (light green). Metric definitions are listed in appendix 1.]

Metric abbreviation	pFC_rich	GC_rich	pGC_rich	pOM_rich	PR_rich	SC_abund	SC_rich	SH_rich	Margalef
Water chemistry, spring									
SPCOND	0.14	-0.18	0.16	-0.30	-0.29	-0.24	-0.13	-0.11	-0.13
CHLOR	.28	-.34	.00	-.18	-.30	-.36	-.26	-.14	-.20
NITRITE	-.32	.08	.20	.21	-.07	-.30	-.13	-.35	-.10
TPCONC	-.22	.13	.10	.18	-.10	-.18	.01	.08	.03
TICONC	.14	-.33	.19	.01	-.37	-.47	-.55	-.30	-.50
PTI_CLAD	.04	-.21	.28	-.02	-.29	-.41	-.53	-.17	-.32
PTI_INV	-.02	-.25	.24	.07	-.47	-.48	-.50	-.15	-.39
Water chemistry, summer									
SPCOND	.25	-.14	.10	-.04	-.20	-.52	-.28	-.37	.00
CHLOR	.21	-.22	.07	-.04	-.12	-.67	-.41	-.47	-.06
NITRITE	-.10	.21	.08	-.10	.17	-.15	.14	-.07	.22
TPCONC	-.31	.11	.57	-.29	-.43	-.09	-.16	.23	-.22
PTI_CLAD	-.24	-.17	.26	-.19	-.32	-.24	-.34	.19	-.30
PTI_INV	-.25	-.23	.14	.07	-.29	-.21	-.41	.08	-.34
PTI_FISH	-.30	.10	.53	-.37	-.44	-.04	-.10	.30	-.17
SPMD chemistry									
TEQ	.18	-.40	-.06	.14	-.19	-.72	-.55	-.52	-.30
UPAH	.36	-.42	-.22	.14	-.11	-.76	-.48	-.54	-.21
S_PCA	-.06	-.18	-.03	.11	.14	-.61	-.47	-.42	-.10
S_FLUOR	.38	-.44	-.21	.15	-.10	-.72	-.51	-.61	-.25
S_PHENA	.42	-.46	-.23	.09	-.07	-.68	-.51	-.55	-.24
S_PYRE	.38	-.44	-.19	.12	-.10	-.72	-.51	-.62	-.24
DETECTS	.17	-.43	-.08	.08	-.18	-.62	-.51	-.52	-.39

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Appendix 6. Spearman rank correlations between metrics computed from fish assemblages and environmental metrics for 30 sites in the Milwaukee to Green Bay, Wis., study area.

[SPMD, semipermeable membrane device. Except for pre-ice and post-ice period hydrology and SPMD metrics; n = 30, for p ≤ 0.001 rho = 0.580 (dark green); for p ≤ 0.01 rho = 0.467 (green), for p ≤ 0.05 rho = 0.362 (light green). Pre-ice period hydrologic condition metrics are area based; n = 22, for p ≤ 0.001 rho = 0.667 (dark green), for p ≤ 0.01 rho = 0.544 (green), for p ≤ 0.05 rho = 0.423 (light green). Post-ice period hydrologic condition metrics are area based; n = 24, p ≤ 0.001 rho = 0.642 (dark green), for p ≤ 0.01 rho = 0.521 (green), for p ≤ 0.05 rho = 0.404 (light green). SPMD metrics; n = 28, for p ≤ 0.001 rho = 0.598 (dark green), for p ≤ 0.01 rho = 0.483 (green), for p ≤ 0.05 rho = 0.375 (light green). Metric abbreviations are listed in appendix 1.]

Metric abbreviation	fDCA axis 1	fDCA axis 2	fDCA axis 3	fDCA axis 4	IBI Score	NATIVE_LY	TOLR_LY	OMNI_LY	INSC_LY	LITHO_LY
Land use/land cover, latitude, and area										
UII	0.14	0.39	0.36	0.31	-0.39	-0.45	-0.33	-0.14	-0.46	-0.45
POPDEN00	.15	.43	.30	.30	-.43	-.48	-.33	-.13	-.48	-.44
NLCD_BIS	.16	.57	.21	.31	-.54	-.57	-.34	-.05	-.63	-.51
NLCD_IS	.13	.53	.30	.29	-.51	-.53	-.33	-.09	-.57	-.50
RDTRDEN	.09	.38	.34	.34	-.42	-.49	-.30	-.06	-.47	-.46
PNLCD_21 ÷ P_NLCD1_2	-.06	-.68	.02	.00	.80	.74	.43	.22	.83	.59
PNLCD_23	.13	.59	.21	.30	-.57	-.60	-.35	-.08	-.64	-.54
PNLCD_24	.14	.58	.31	.27	-.53	-.55	-.38	-.12	-.64	-.54
pwNLCD_23	.19	.50	.16	.37	-.57	-.66	-.48	-.17	-.67	-.58
pwNLCD_24	.16	.52	.26	.20	-.55	-.62	-.45	-.25	-.65	-.57
P_NLCD1_B4	-.16	-.51	-.01	.07	.48	.48	.33	-.04	.59	.39
P_NLCD1_4	.01	-.60	.01	-.01	.55	.53	.25	-.11	.50	.38
PNLCD_41	.03	-.63	-.03	.06	.53	.48	.19	-.14	.49	.31
PNLCD_42	.05	-.31	.15	-.16	.55	.50	.18	-.08	.37	.39
PNLCD_43	-.13	-.58	.28	.01	.67	.63	.15	-.14	.54	.37
pwNLCD_42	.02	-.41	.11	-.32	.63	.59	.25	-.03	.51	.48
pwNLCD_43	-.14	-.50	.24	-.21	.68	.65	.18	-.15	.56	.42
P_NLCD1_B9	.04	-.48	.15	-.14	.70	.66	.20	-.10	.57	.33
P_NLCD1_9	-.04	-.57	-.04	-.22	.63	.69	.31	.01	.58	.42
PNLCD_90	-.15	-.54	.07	-.20	.63	.68	.31	.03	.58	.42
PNLCD_95	.13	-.46	-.05	-.23	.50	.57	.20	-.12	.45	.30
pwNLCD_90	-.21	-.41	.13	-.26	.56	.67	.34	.02	.58	.47
pwNLCD_95	.13	-.42	-.12	-.19	.55	.55	.15	-.25	.43	.20
SLOPE_X	-.09	-.59	.32	.12	.63	.50	-.02	-.28	.40	.24
LATITUDE	-.03	-.29	-.41	.00	.22	.10	.36	.33	.38	.44

TAXAfish	ABUNfish	OMNIfshE	INSCfshE	GENRfshE	INTMfshE	TOLRfshE	COBBfish	MUDfish	ACCLfish	SIMPfish	COMPfish
Land use/land cover, latitude, and area											
-0.44	-0.42	0.29	-0.27	0.08	-0.30	0.30	0.04	-0.28	-0.62	-0.02	-0.06
-.47	-.44	.32	-.33	.12	-.33	.33	.11	-.30	-.63	.05	-.11
-.55	-.53	.50	-.46	.10	-.45	.47	.16	-.25	-.65	.00	-.14
-.51	-.49	.42	-.40	.13	-.41	.42	.17	-.29	-.67	.04	-.13
-.47	-.42	.39	-.28	.09	-.37	.37	.07	-.15	-.68	.00	-.02
.70	.68	-.54	.56	-.25	.53	-.58	-.36	.49	.37	-.15	.39
-.58	-.55	.50	-.48	.15	-.49	.49	.23	-.30	-.69	.04	-.16
-.54	-.55	.44	-.41	.13	-.40	.41	.20	-.32	-.63	.02	-.15
-.65	-.63	.48	-.46	.05	-.36	.37	.15	-.28	-.65	-.06	-.15
-.61	-.60	.36	-.37	.09	-.34	.36	.14	-.35	-.54	-.04	-.16
.45	.48	-.60	.46	-.05	.31	-.34	-.30	.05	.30	-.04	.32
.52	.42	-.56	.47	-.11	.35	-.41	-.27	.17	.39	.00	.21
.45	.37	-.56	.49	-.15	.34	-.39	-.32	.19	.44	-.05	.26
.52	.36	-.45	.25	-.04	.31	-.39	-.07	.04	.16	.01	.03
.61	.45	-.59	.51	-.10	.54	-.60	-.28	.16	.22	.01	.24
.61	.46	-.50	.37	-.06	.39	-.45	-.10	.14	.32	.02	.07
.66	.47	-.60	.51	-.02	.54	-.61	-.20	.18	.28	.06	.18
.65	.43	-.56	.57	-.12	.50	-.57	-.25	.24	.47	-.03	.33
.68	.50	-.53	.47	-.09	.46	-.51	-.16	.24	.60	.01	.21
.67	.51	-.51	.49	-.01	.50	-.54	-.17	.24	.46	.02	.24
.55	.37	-.50	.42	-.14	.33	-.38	-.12	.25	.70	.03	.13
.68	.52	-.52	.42	.15	.47	-.53	-.05	.09	.35	.18	.12
.56	.32	-.60	.41	-.07	.29	-.37	-.10	.10	.65	.11	.07
.47	.29	-.60	.36	-.12	.48	-.57	-.34	.13	.15	.05	.10
.06	.33	-.10	.14	-.22	.11	-.07	-.20	.21	.27	-.28	.24

Appendix 6. Spearman rank correlations between metrics computed from fish assemblages and environmental metrics for 30 sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[SPMD, semipermeable membrane device. Except for pre-ice and post-ice period hydrology and SPMD metrics; n = 30, for p ≤ 0.001 rho = 0.580 (dark green); for p ≤ 0.01 rho = 0.467 (green), for p ≤ 0.05 rho = 0.362 (light green). Pre-ice period hydrologic condition metrics are area based; n = 22, for p ≤ 0.001 rho = 0.667 (dark green), for p ≤ 0.01 rho = 0.544 (green), for p ≤ 0.05 rho = 0.423 (light green). Post-ice period hydrologic condition metrics are area based; n = 24, p ≤ 0.001 rho = 0.642 (dark green), for p ≤ 0.01 rho = 0.521 (green), for p ≤ 0.05 rho = 0.404 (light green). SPMD metrics; n = 28, for p ≤ 0.001 rho = 0.598 (dark green), for p ≤ 0.01 rho = 0.483 (green), for p ≤ 0.05 rho = 0.375 (light green). Metric abbreviations are listed in appendix 1.]

Metric abbreviation	fDCA axis 1	fDCA axis 2	fDCA axis 3	fDCA axis 4	IBI Score	NATIVE_LY	TOLR_LY	OMNI_LY	INSC_LY	LITHO_LY
Habitat										
RipLU	0.02	0.27	0.51	-0.02	-0.16	-0.06	-0.11	0.00	-0.30	-0.04
BFDepthNoPools	-.03	.49	-.20	-.09	-.36	-.40	-.04	.10	-.32	-.05
GCUTypeRiffPct	-.31	-.07	.60	-.16	.12	.17	.11	.14	.08	.26
GCUTypePoolPct	.00	-.61	.15	.08	.58	.66	.26	.22	.55	.21
GCUTypeRunPct	.16	.50	-.37	.04	-.55	-.62	-.24	-.19	-.45	-.32
GCUTypePoolRiff	.03	-.55	-.04	.10	.52	.56	.34	.26	.57	.17
WidthDepthAvg	-.09	-.18	.56	-.26	.19	.41	.18	.04	.14	.28
ChShpCV	-.13	.12	.60	.07	.00	.10	.07	.21	-.02	.09
Froude	-.05	-.01	.49	.05	.22	.19	.06	-.04	.12	.31
BedSubStab	-.26	-.10	.54	.06	.22	.14	.04	.03	.15	.37
BankVegCovPct	.01	-.47	-.15	-.28	.29	.11	.28	.11	.35	.41
Hydrology, pre-ice period (Oct. 1 to Dec. 8, 2003)										
day_pctchange	.15	.55	.08	.12	-.51	-.69	-.46	-.18	-.64	-.42
rb_flash	.20	.40	-.05	.19	-.46	-.67	-.50	-.22	-.59	-.42
MXH_95	-.07	-.23	-.37	-.40	.40	.36	.47	.08	.50	.61
Hydrology, post-ice period (Mar. 16 to Oct. 30, 2004)										
day_pctchange	.08	.06	.09	.16	-.09	-.28	-.40	-.31	-.26	-.14
rb_flash	-.03	.04	.02	.17	-.10	-.21	-.32	-.29	-.23	-.07
periodr1	-.11	-.53	.39	.26	.65	.69	.11	.19	.60	.28
periodr9	.20	.49	.19	.38	-.51	-.52	-.47	-.25	-.64	-.59
MDH_90	-.12	-.16	-.10	-.48	.28	.36	.49	.21	.49	.67
MDH_95	-.02	-.30	-.27	-.43	.49	.45	.31	.13	.44	.50
Hydrology (annual streamflow)										
Q_bnkfl	-.27	.23	.27	-.17	-.25	-.09	.15	.14	-.18	.24
Q_bnkflDA	-.18	.24	.45	.19	-.16	-.21	-.14	-.04	-.20	.03
Qmax_instDA	-.11	.29	.16	.14	-.49	-.27	-.49	-.28	-.56	-.40
INSTDIS - spring	-.19	-.25	.30	-.27	.28	.38	.02	-.29	.20	.11
INSTDIS - summer	.00	.09	.30	-.17	.08	.11	.06	.00	-.01	.16

TAXAfish	ABUNfish	OMNIfshE	INSCfshE	GENRfshE	INTMfshE	TOLRfshE	COBBfish	MUDfish	ACCLfish	SIMPfish	COMPfish
Habitat											
-0.04	-0.14	0.20	-0.38	0.19	-0.18	0.14	0.25	-0.10	-0.39	0.19	-0.32
-.37	-.18	.35	-.34	.23	-.27	.30	.40	-.43	-.37	.15	-.31
.18	.13	-.06	-.05	.24	.08	-.13	.21	-.07	-.33	.20	-.13
.65	.41	-.25	.53	-.40	.23	-.29	-.32	.28	.22	-.11	.47
-.62	-.38	.27	-.35	.16	-.22	.31	.07	-.21	-.06	-.04	-.25
.54	.42	-.24	.62	-.40	.10	-.14	-.41	.28	.34	-.19	.58
.45	.23	-.23	-.04	.11	.19	-.21	.02	-.14	-.07	.24	-.18
.13	.05	.12	-.17	.12	.04	-.01	.10	.02	-.52	.24	.00
.16	.15	-.24	-.04	-.05	.19	-.23	.11	-.11	-.20	.05	-.18
.13	.18	-.17	.00	.28	.25	-.29	.12	-.04	-.19	.31	-.16
.13	.35	-.22	.18	-.17	.17	-.19	-.20	.12	.23	-.03	-.04
Hydrology, pre-ice period (Oct. 1 to Dec. 8, 2003)											
-.66	-.57	.27	-.50	-.03	-.19	.22	.10	-.57	-.52	-.18	-.29
-.66	-.58	.24	-.39	-.11	-.16	.18	.05	-.51	-.38	-.24	-.23
.37	.52	-.34	.20	-.06	.27	-.19	-.14	.19	.60	-.11	.14
Hydrology, post-ice period (Mar. 16 to Oct. 30, 2004)											
-.27	-.32	-.03	-.23	-.06	.14	-.15	-.02	-.50	-.39	-.06	-.26
-.19	-.25	-.06	-.25	.06	.09	-.11	.08	-.52	-.38	.06	-.33
.65	.44	-.25	.52	-.40	.59	-.61	-.40	.60	.13	-.19	.47
-.49	-.62	.41	-.27	-.07	-.27	.27	.09	-.42	-.57	-.10	.03
.36	.56	-.30	.23	.01	.14	-.09	-.04	.15	.49	.08	-.01
.43	.47	-.35	.22	-.13	.28	-.24	-.12	.21	.68	-.04	-.05
Hydrology (annual streamflow)											
-.08	.03	.06	-.45	.49	-.20	.20	.45	-.62	-.42	.49	-.57
-.21	-.13	.01	-.39	.41	-.07	.05	.20	-.44	-.67	.42	-.42
-.23	-.50	.38	-.48	.21	-.15	.12	.27	-.28	-.49	.27	-.45
.40	.16	-.44	.32	.14	.33	-.40	-.01	-.15	.23	.23	-.11
.12	.07	-.10	-.08	.04	.07	-.08	.19	-.35	-.12	.18	-.26

Appendix 6. Spearman rank correlations between metrics computed from fish assemblages and environmental metrics for 30 sites in the Milwaukee to Green Bay, Wis., study area—Continued.

[SPMD, semipermeable membrane device. Except for pre-ice and post-ice period hydrology and SPMD metrics; n = 30, for p ≤ 0.001 rho = 0.580 (dark green); for p ≤ 0.01 rho = 0.467 (green), for p ≤ 0.05 rho = 0.362 (light green). Pre-ice period hydrologic condition metrics are area based; n = 22, for p ≤ 0.001 rho = 0.667 (dark green), for p ≤ 0.01 rho = 0.544 (green), for p ≤ 0.05 rho = 0.423 (light green). Post-ice period hydrologic condition metrics are area based; n = 24, p ≤ 0.001 rho = 0.642 (dark green), for p ≤ 0.01 rho = 0.521 (green), for p ≤ 0.05 rho = 0.404 (light green). SPMD metrics; n = 28, for p ≤ 0.001 rho = 0.598 (dark green), for p ≤ 0.01 rho = 0.483 (green), for p ≤ 0.05 rho = 0.375 (light green). Metric abbreviations are listed in appendix 1.]

Metric abbreviation	fDCA axis 1	fDCA axis 2	fDCA axis 3	fDCA axis 4	IBI Score	NATIVE_LY	TOLR_LY	OMNI_LY	INSC_LY	LITHO_LY
Water chemistry, spring										
DISSOX	0.06	0.10	0.14	0.27	-0.14	-0.02	0.00	0.26	-0.20	0.11
BICARB	.03	.05	-.28	.60	-.14	-.26	-.06	-.04	.01	-.26
SPCOND	.05	.41	.10	.28	-.52	-.46	.00	.28	-.38	-.30
CHLOR	.09	.45	.15	.22	-.51	-.47	-.04	.23	-.44	-.33
SULFA	.02	.52	-.06	.29	-.57	-.52	.07	.28	-.38	-.23
ACETO	.40	.53	-.06	-.05	-.29	-.42	-.04	-.08	-.34	-.34
NUMP	.38	.60	.15	.04	-.36	-.43	-.33	-.21	-.50	-.39
NUMH	.40	.65	.25	.01	-.34	-.36	-.30	-.13	-.48	-.41
TICONC	.18	.43	-.17	.12	-.46	-.53	-.30	-.26	-.47	-.33
PTI_CLAD	.06	.45	.02	.09	-.42	-.48	-.31	-.24	-.47	-.24
PTI_INV	.14	.50	.09	-.13	-.58	-.41	-.25	-.21	-.48	-.35
PTI_FISH	.14	.47	-.21	-.27	-.35	-.33	-.23	-.21	-.36	-.25
Water chemistry, summer										
DISSOX	-.52	-.07	.10	-.19	-.04	.17	.21	.06	.06	.36
BICARB	-.29	-.53	-.06	.11	.49	.49	.06	-.12	.56	.24
CHLOR	.13	.37	.23	.24	-.37	-.40	-.27	-.10	-.36	-.52
SULFA	-.03	.31	-.14	.30	-.33	-.14	.07	.23	-.21	-.29
TPCONC	-.01	.38	-.11	-.41	-.40	-.43	.12	.13	-.20	.11
NUMP	-.04	.41	.16	-.16	-.34	-.29	-.05	-.02	-.32	.14
PTI_CLAD	-.09	.37	.06	-.10	-.62	-.52	-.11	-.03	-.41	-.04
PTI_INV	.16	.40	.08	-.19	-.53	-.45	-.15	-.06	-.43	-.08
PTI_FISH	-.16	.33	-.04	-.30	-.50	-.44	.11	.19	-.23	.12
SPMD chemistry										
TEQ	.18	.52	.27	.26	-.43	-.55	-.43	-.25	-.51	-.50
UPAH	.20	.48	.33	.22	-.37	-.54	-.37	-.25	-.47	-.49
S_PCA	.28	.28	.05	.16	-.31	-.53	-.49	-.43	-.43	-.44
S_FLUOR	.17	.44	.29	.28	-.36	-.54	-.44	-.36	-.50	-.50
S_PHENA	.11	.41	.34	.33	-.32	-.46	-.36	-.28	-.44	-.40
S_PYRE	.15	.43	.30	.30	-.35	-.52	-.44	-.37	-.49	-.50
DETECTS	.10	.38	.25	.26	-.38	-.55	-.45	-.42	-.48	-.42

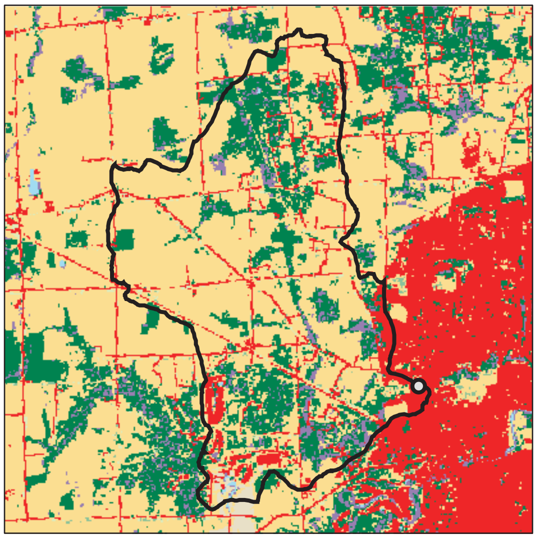
TAXAfish	ABUNfish	OMNIfshE	INSCfshE	GENRfshE	INTMfshE	TOLRfshE	COBBfish	MUDfish	ACCLfish	SIMPfish	COMPfish
Water chemistry, spring											
-0.01	-0.08	0.36	-0.47	-0.01	-0.10	0.07	0.26	0.02	-0.39	0.18	-0.28
-.31	-.08	.04	.04	-.14	-.25	.27	-.16	.14	.04	-.12	.32
-.45	-.27	.52	-.41	.03	-.52	.56	.16	-.18	-.59	-.07	-.05
-.46	-.31	.50	-.42	.03	-.52	.55	.18	-.25	-.63	-.10	-.03
-.50	-.24	.52	-.44	.11	-.51	.55	.29	-.11	-.55	-.05	-.10
-.39	-.29	.15	-.06	-.09	-.53	.56	.02	-.26	-.13	-.26	.09
-.41	-.48	.21	-.22	-.01	-.25	.28	.06	-.56	-.33	-.15	-.18
-.33	-.45	.28	-.21	.01	-.25	.28	.09	-.41	-.37	-.10	-.14
-.55	-.43	.10	-.37	.15	-.36	.37	.22	-.65	-.23	.05	-.35
-.49	-.41	.08	-.41	.11	-.22	.26	.13	-.67	-.42	-.02	-.31
-.40	-.41	.16	-.40	.20	-.28	.33	.16	-.64	-.31	.12	-.41
-.30	-.32	.09	-.25	.09	-.06	.12	.14	-.40	.10	-.06	-.34
Water chemistry, summer											
.20	.24	-.13	-.24	.43	.07	-.08	.43	-.15	-.03	.44	-.45
.45	.36	-.48	.50	.02	.48	-.51	-.20	.11	.38	.08	.29
-.41	-.39	.26	-.04	.09	-.35	.37	-.04	-.20	-.36	-.17	.20
-.16	-.12	.32	-.24	.21	-.38	.35	.40	-.05	-.20	.04	-.10
-.42	-.02	.18	-.33	.21	-.22	.34	.13	-.20	.00	-.01	-.32
-.27	-.11	.24	-.49	.12	-.11	.16	.22	-.06	-.29	.10	-.45
-.52	-.23	.30	-.52	.26	-.21	.28	.21	-.21	-.38	.16	-.48
-.42	-.25	.28	-.48	.20	-.17	.26	.11	-.32	-.34	.15	-.48
-.44	-.04	.27	-.42	.30	-.21	.32	.21	-.18	-.16	.11	-.38
SPMD chemistry											
-.56	-.50	.21	-.28	.04	-.21	.27	-.03	-.47	-.52	-.14	-.07
-.55	-.50	.17	-.21	.07	-.30	.33	.03	-.38	-.52	-.08	.06
-.52	-.45	.10	-.15	.05	-.19	.21	-.01	-.23	-.30	-.04	-.09
-.54	-.52	.12	-.21	.07	-.30	.31	.02	-.42	-.48	-.07	.01
-.47	-.44	.13	-.24	.07	-.30	.30	.04	-.40	-.54	-.05	.01
-.53	-.52	.11	-.21	.07	-.29	.30	.02	-.42	-.49	-.06	.01
-.56	-.47	.06	-.26	.05	-.11	.17	-.08	-.49	-.43	-.04	-.13

Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

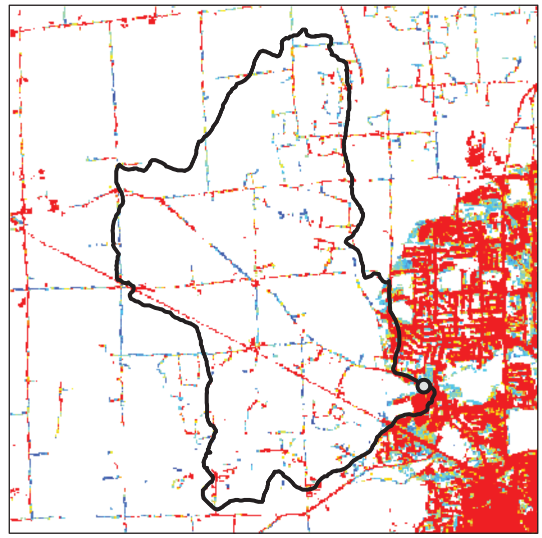
Lancaster Brook at Shawano Ave. at Howard, Wis.

(LANC; site 1; urban intensity index value = 33.33)

A. 2001 Land cover (developed land = 11.66 percent)



B. Impervious surface (mean = 2.86 percent)



EXPLANATION

2001 Land cover

- Open water
- Developed
- Barren
- Forest
- Shrub/scrub
- Grassland/herbaceous
- Cultivated crops/pasture
- Wetlands
- Study watershed boundary
- Sampling site

EXPLANATION

2001 Impervious surface, in percent

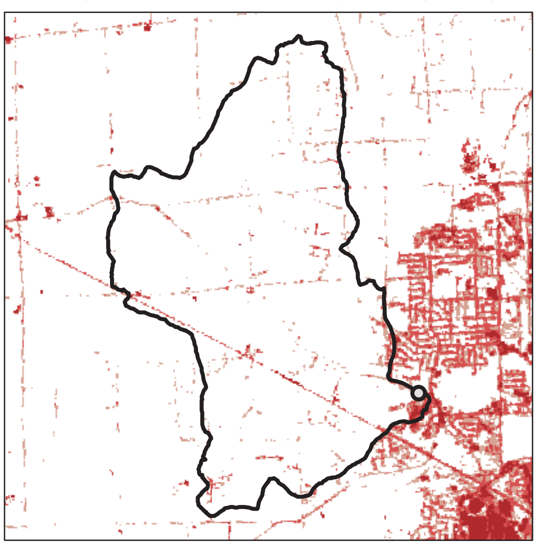
High : 100

Low : 0

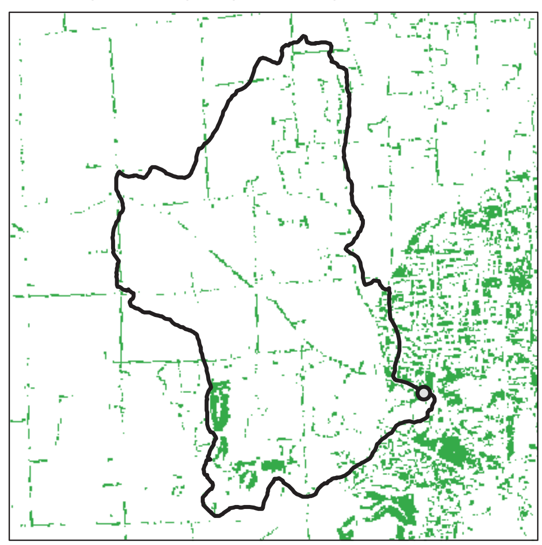
Study watershed boundary

Sampling site

C. Developed land (low, medium and high intensity = 5.27 percent)



D. Developed land (open space = 6.39 percent)



EXPLANATION

2001 Land cover

- Developed, low density
- Developed, medium density
- Developed, high density
- Study watershed boundary
- Sampling site

0 1 2 MILES

0 1 2 KILOMETERS

EXPLANATION

2001 Land cover

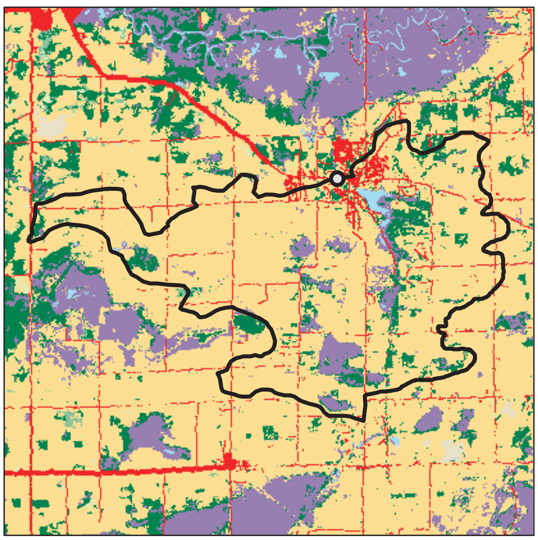
- Developed, open space
- Study watershed boundary
- Sampling site

Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed

Black Otter Creek near Hortonville, Wis.

(BLOT; site 2; urban intensity index value = 26.49)

A. 2001 Land cover (developed land = 5.36 percent)

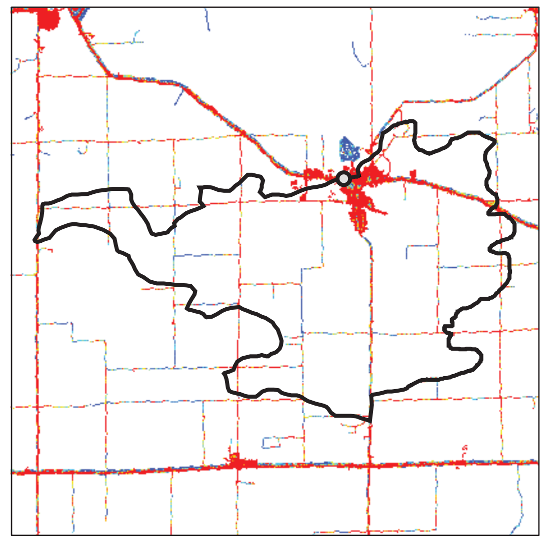


EXPLANATION

2001 Land cover

- Open water
- Developed
- Barren
- Forest
- Shrub/scrub
- Grassland/herbaceous
- Cultivated crops/pasture
- Wetlands
- Study watershed boundary
- Sampling site

B. Impervious surface (mean = 1.87 percent)



EXPLANATION

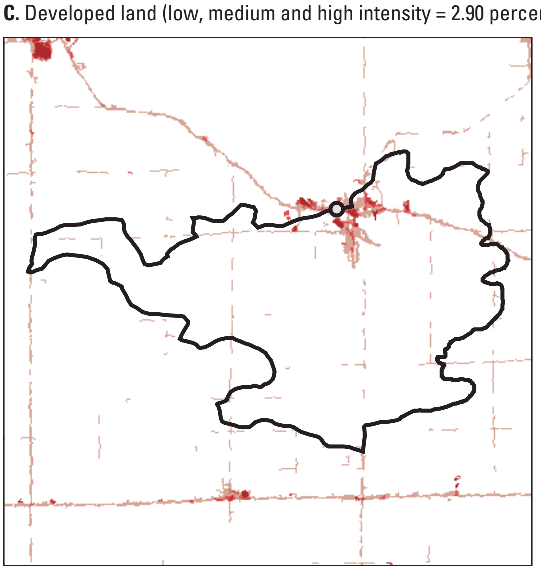
2001 Impervious surface, in percent

High : 100

Low : 0

- Study watershed boundary
- Sampling site

C. Developed land (low, medium and high intensity = 2.90 percent)

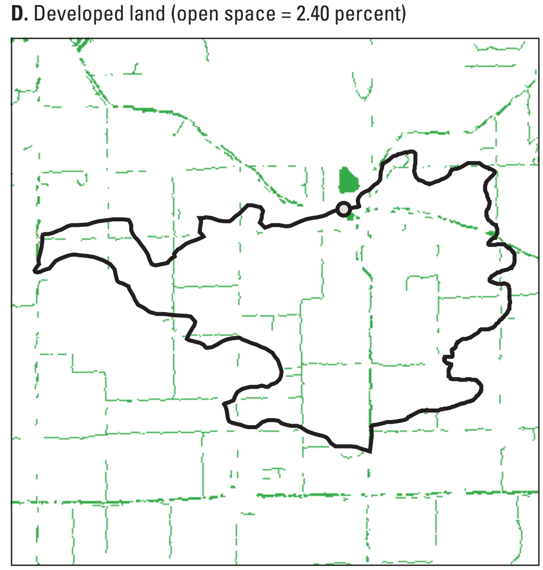


EXPLANATION

2001 Land cover

- Developed, low density
- Developed, medium density
- Developed, high density
- Study watershed boundary
- Sampling site

D. Developed land (open space = 2.40 percent)



EXPLANATION

2001 Land cover

- Developed, open space
- Study watershed boundary
- Sampling site

0 2 4 MILES

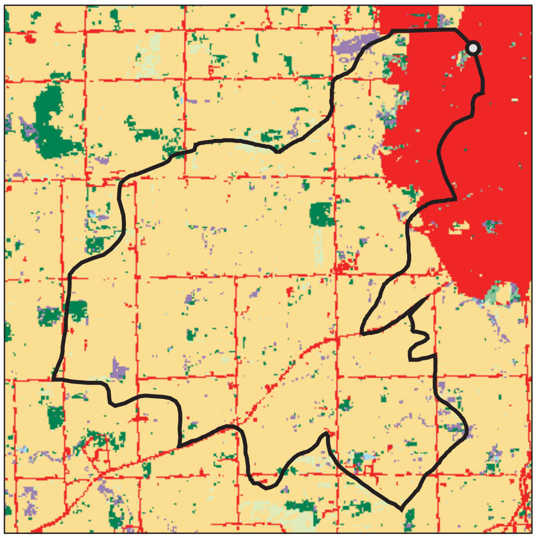
0 2 4 KILOMETERS

Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

Sawyer Creek at Westhaven Rd. at Oshkosh, Wis.

(SAWY; site 3; urban intensity index value = 32.60)

A. 2001 Land cover (developed land = 13.80 percent)

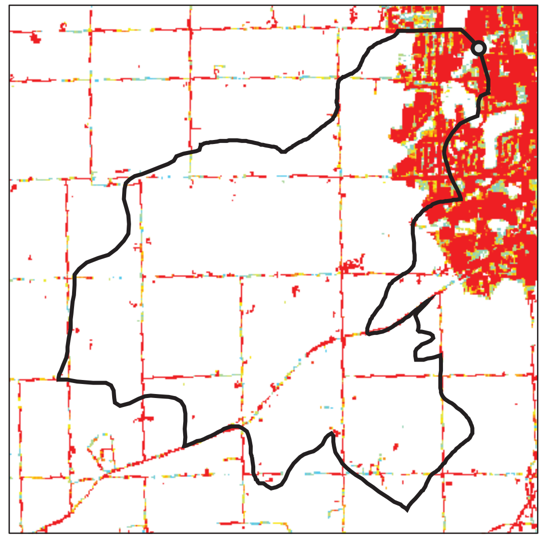


EXPLANATION

2001 Land cover

- Open water
- Developed
- Barren
- Forest
- Shrub/scrub
- Grassland/herbaceous
- Cultivated crops/pasture
- Wetlands
- Study watershed boundary
- Sampling site

B. Impervious surface (mean = 4.87 percent)



EXPLANATION

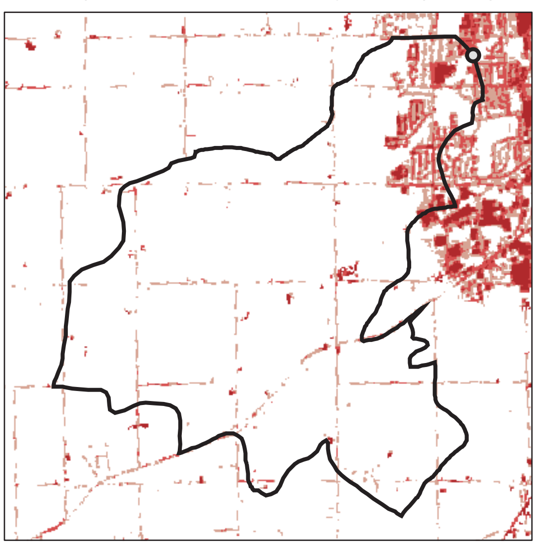
2001 Impervious surface, in percent

High : 100

Low : 0

- Study watershed boundary
- Sampling site

C. Developed land (low, medium and high intensity = 9.06 percent)

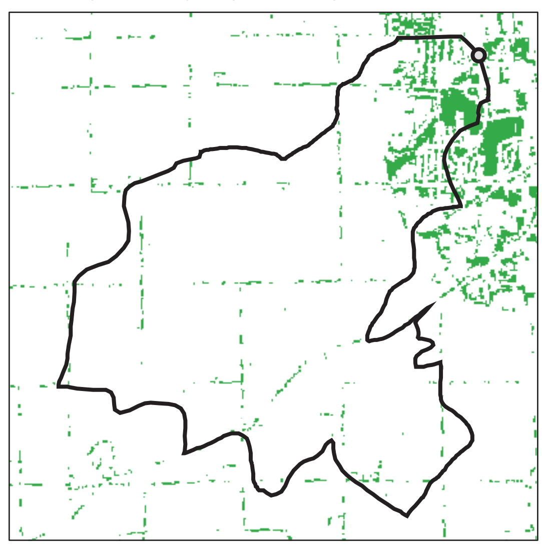


EXPLANATION

2001 Land cover

- Developed, low density
- Developed, medium density
- Developed, high density
- Study watershed boundary
- Sampling site

D. Developed land (open space = 4.82 percent)



EXPLANATION

2001 Land cover

- Developed, open space
- Study watershed boundary
- Sampling site

0 1 2 MILES

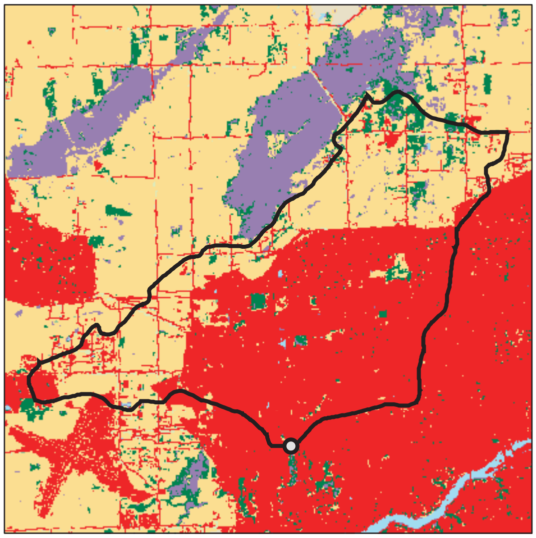
0 1 2 KILOMETERS

Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

Mud Creek at Spencer Rd. at Appleton, Wis.

(MUDC; site 4; urban intensity index value = 33.33)

A. 2001 Land cover (developed land = 58.83 percent)

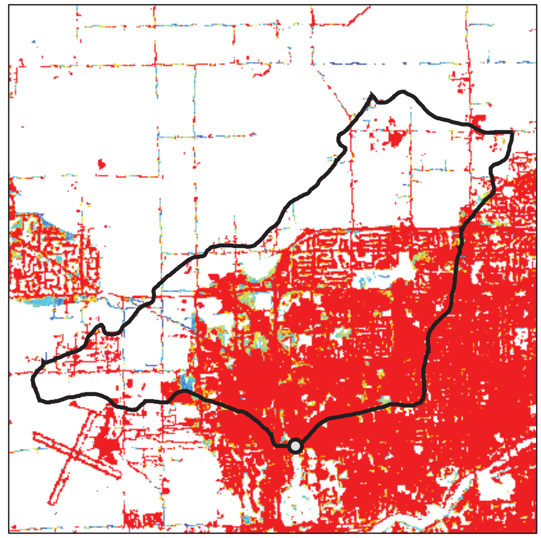


EXPLANATION

2001 Land cover

- Open water
- Developed
- Barren
- Forest
- Shrub/scrub
- Grassland/herbaceous
- Cultivated crops/pasture
- Wetlands
- Study watershed boundary
- Sampling site

B. Impervious surface (mean = 30.33 percent)



EXPLANATION

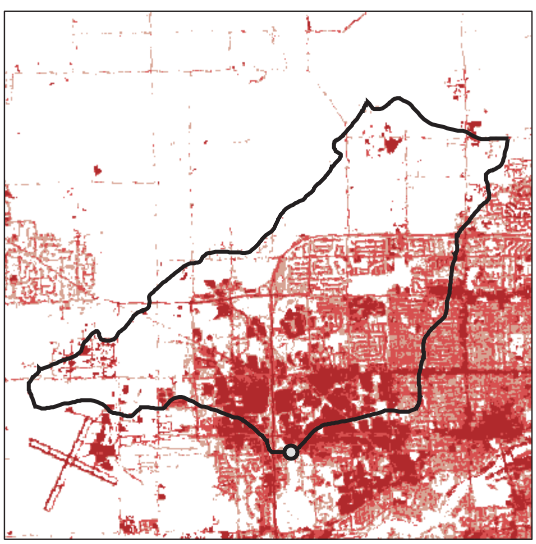
2001 Impervious surface, in percent

High : 100

Low : 0

- Study watershed boundary
- Sampling site

C. Developed land (low, medium and high intensity = 46.30 percent)



EXPLANATION

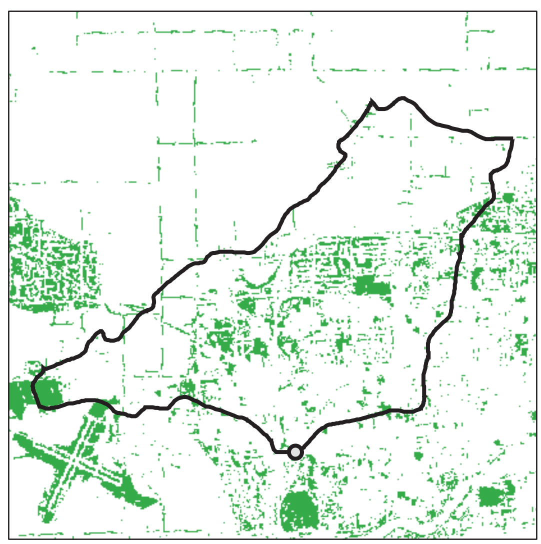
2001 Land cover

- Developed, low density
- Developed, medium density
- Developed, high density
- Study watershed boundary
- Sampling site

0 2 4 MILES

0 2 4 KILOMETERS

D. Developed land (open space = 12.53 percent)



EXPLANATION

2001 Land cover

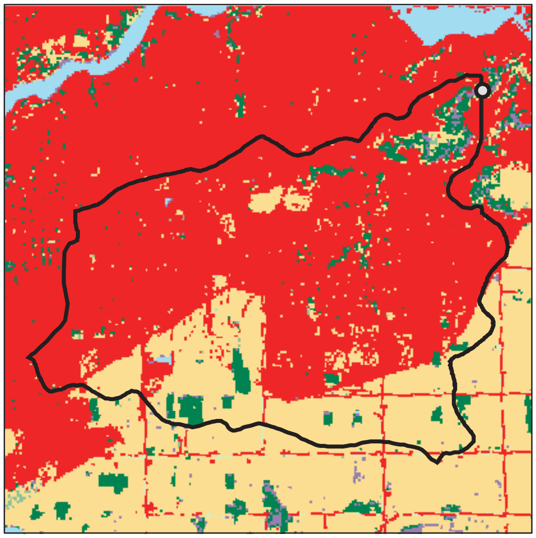
- Developed, open space
- Study watershed boundary
- Sampling site

Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

Garners Creek at Park St. at Kaukauna, Wis.

(GARN; site 5; urban intensity index value = 60.03)

A. 2001 Land cover (developed land = 68.95 percent)

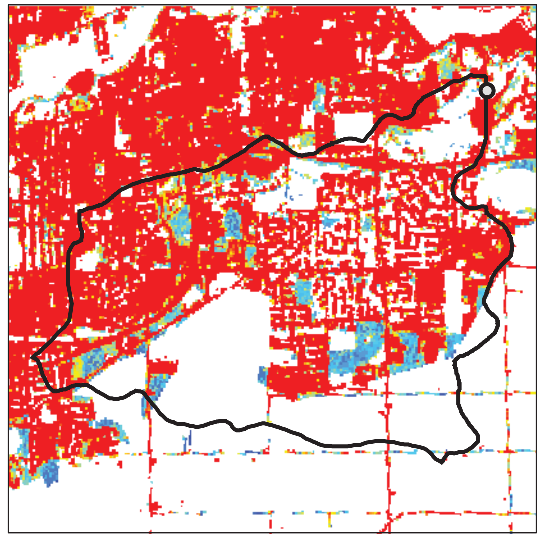


EXPLANATION

2001 Land cover

- Open water
- Developed
- Barren
- Forest
- Shrub/scrub
- Grassland/herbaceous
- Cultivated crops/pasture
- Wetlands
- Study watershed boundary
- Sampling site

B. Impervious surface (mean = 25.91 percent)



EXPLANATION

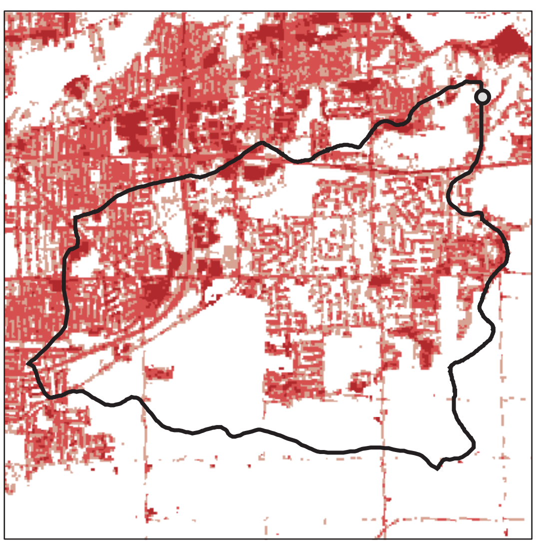
2001 Impervious surface, in percent

High : 100

Low : 0

- Study watershed boundary
- Sampling site

C. Developed land (low, medium and high intensity = 45.34 percent)

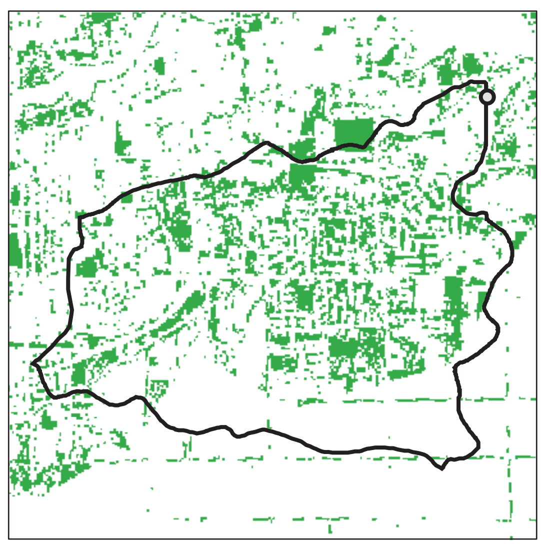


EXPLANATION

2001 Land cover

- Developed, low density
- Developed, medium density
- Developed, high density
- Study watershed boundary
- Sampling site

D. Developed land (open space = 23.61 percent)



EXPLANATION

2001 Land cover

- Developed, open space
- Study watershed boundary
- Sampling site

0 1 2 MILES

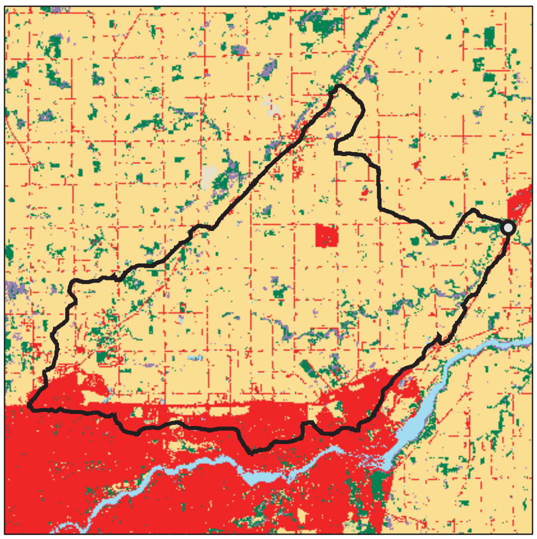
0 1 2 KILOMETERS

Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

Apple Creek at Sniderville, Wis.

(APPL; site 6; urban intensity index value = 33.29)

A. 2001 Land cover (developed land = 17.59 percent)

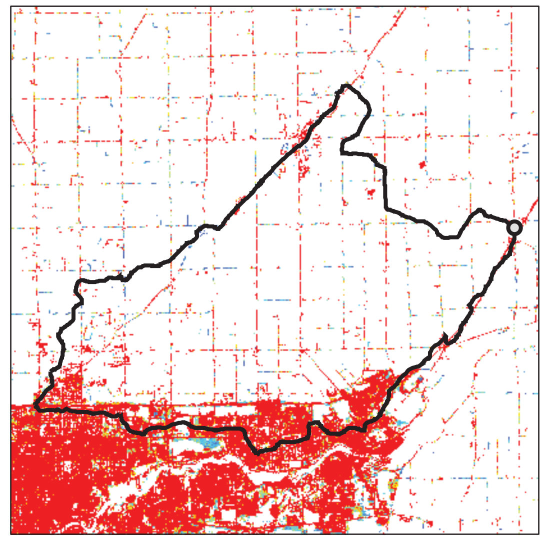


EXPLANATION

2001 Land cover

- Open water
- Developed
- Barren
- Forest
- Shrub/scrub
- Grassland/herbaceous
- Cultivated crops/pasture
- Wetlands
- Study watershed boundary
- Sampling site

B. Impervious surface (mean = 7.64 percent)



EXPLANATION

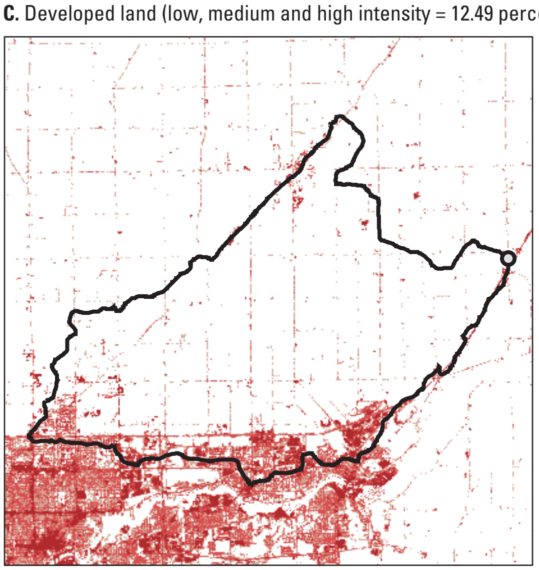
2001 Impervious surface, in percent

High : 100

Low : 0

- Study watershed boundary
- Sampling site

C. Developed land (low, medium and high intensity = 12.49 percent)

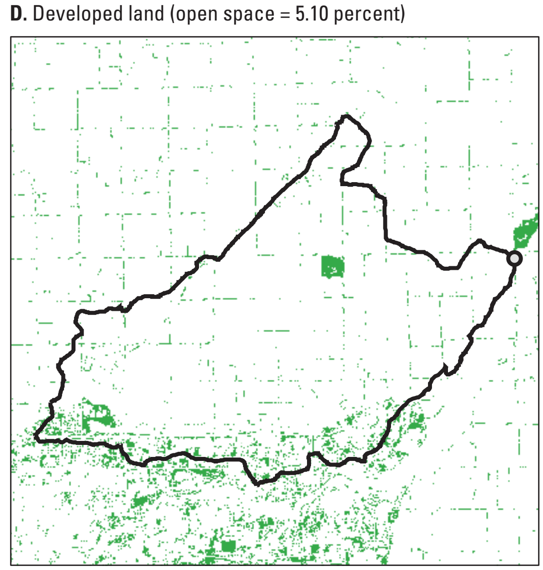


EXPLANATION

2001 Land cover

- Developed, low density
- Developed, medium density
- Developed, high density
- Study watershed boundary
- Sampling site

D. Developed land (open space = 5.10 percent)



EXPLANATION

2001 Land cover

- Developed, open space
- Study watershed boundary
- Sampling site

0 3 6 MILES

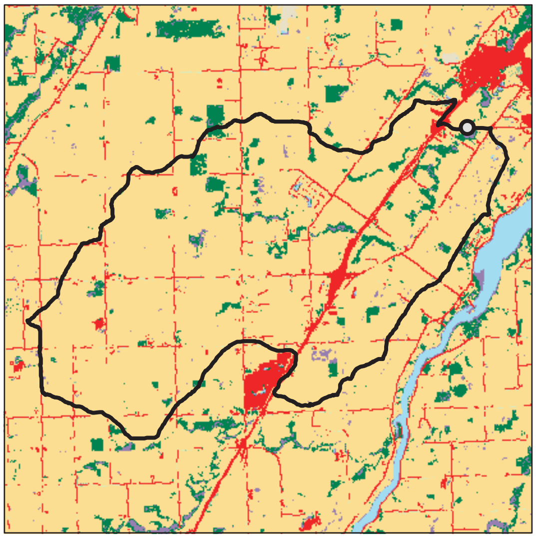
0 3 6 KILOMETERS

Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

Ashwaubenon Creek at South Bridge Rd. near Depere, Wis.

(ASHW; site 7; urban intensity index value = 21.51)

A. 2001 Land cover (developed land = 5.70 percent)

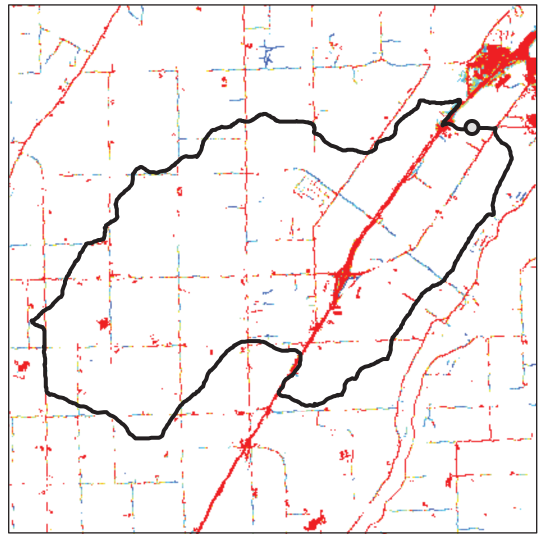


EXPLANATION

2001 Land cover

- Open water
- Developed
- Barren
- Forest
- Shrub/scrub
- Grassland/herbaceous
- Cultivated crops/pasture
- Wetlands
- Study watershed boundary
- Sampling site

B. Impervious surface (mean = 2.43 percent)



EXPLANATION

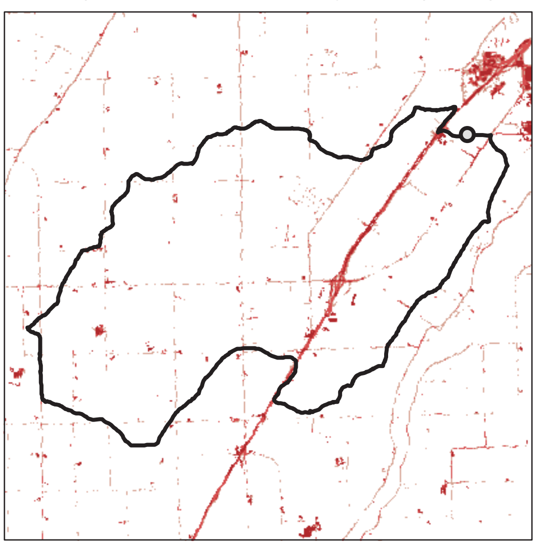
2001 Impervious surface, in percent

High : 100

Low : 0

- Study watershed boundary
- Sampling site

C. Developed land (low, medium and high intensity = 4.00 percent)

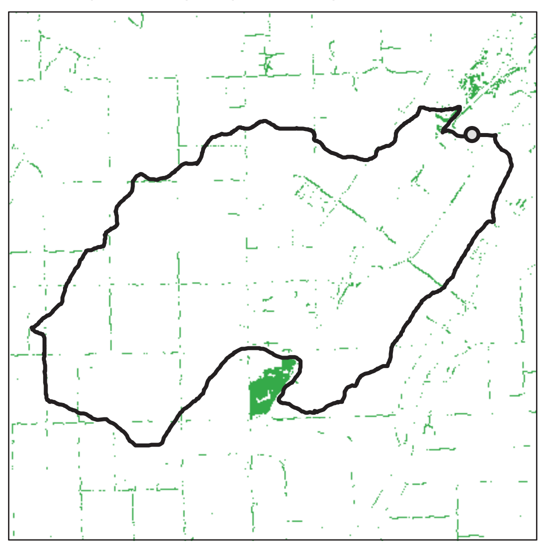


EXPLANATION

2001 Land cover

- Developed, low density
- Developed, medium density
- Developed, high density
- Study watershed boundary
- Sampling site

D. Developed land (open space = 1.65 percent)



EXPLANATION

2001 Land cover

- Developed, open space
- Study watershed boundary
- Sampling site

0 2 4 MILES

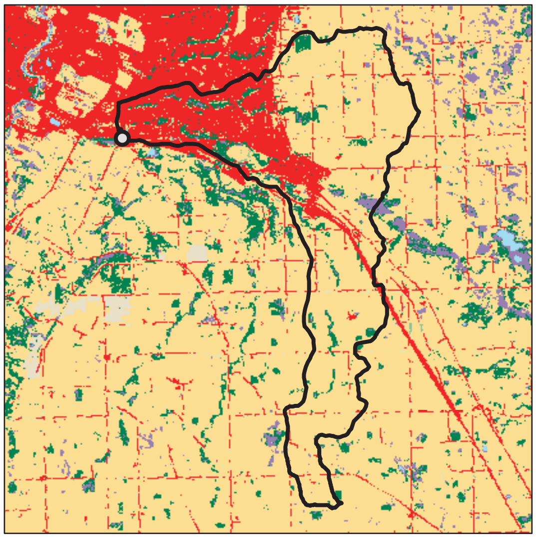
0 2 4 KILOMETERS

Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

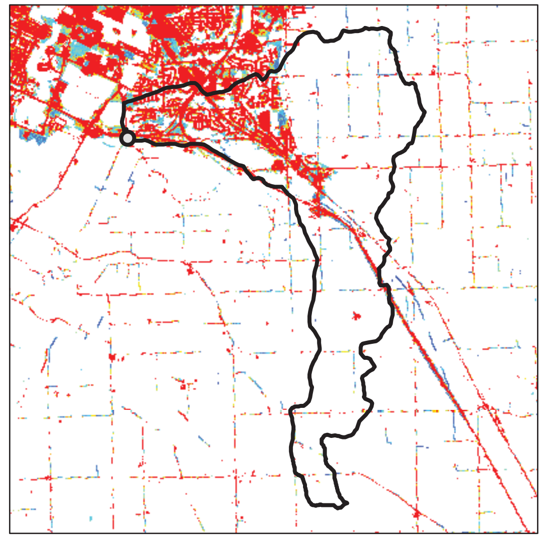
Bower Creek Tributary at Lime Kiln Rd. near Bellevue, Wis.

(BOWR; site 8; urban intensity index value = 37.97)

A. 2001 Land cover (developed land = 24.20 percent)



B. Impervious surface (mean = 8.00 percent)



EXPLANATION

2001 Land cover

Open water
Developed
Barren
Forest
Shrub/scrub
Grassland/herbaceous
Cultivated crops/pasture
Wetlands

Study watershed boundary

Sampling site

EXPLANATION

2001 Impervious surface, in percent

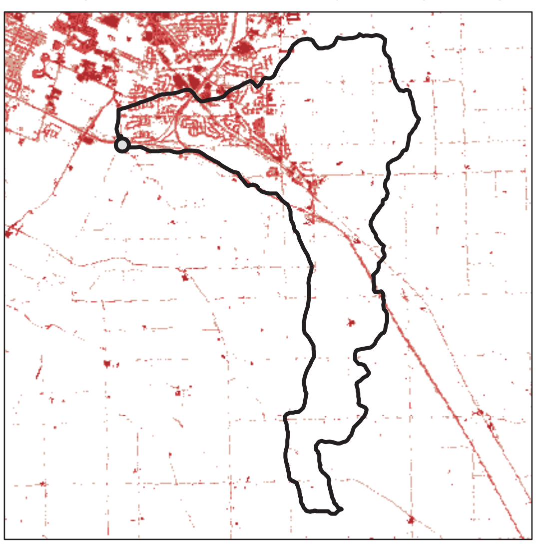
High : 100

Low : 0

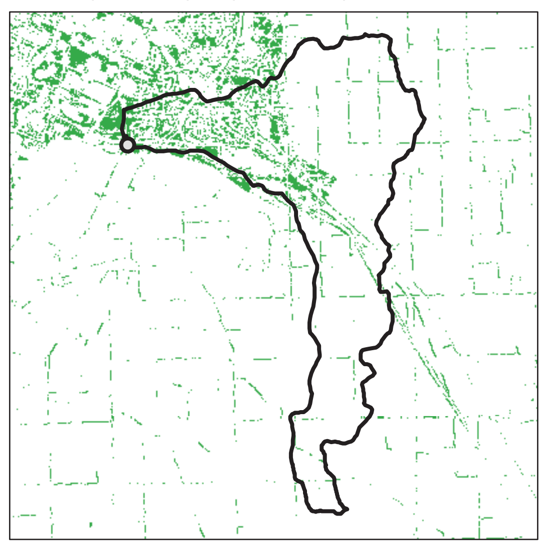
Study watershed boundary

Sampling site

C. Developed land (low, medium and high intensity = 14.38 percent)



D. Developed land (open space = 10.02 percent)



EXPLANATION

2001 Land cover

Developed, low density
Developed, medium density
Developed, high density

Study watershed boundary

Sampling site

0 2.5 5 MILES

0 2.5 5 KILOMETERS

EXPLANATION

2001 Land cover

Developed, open space

Study watershed boundary

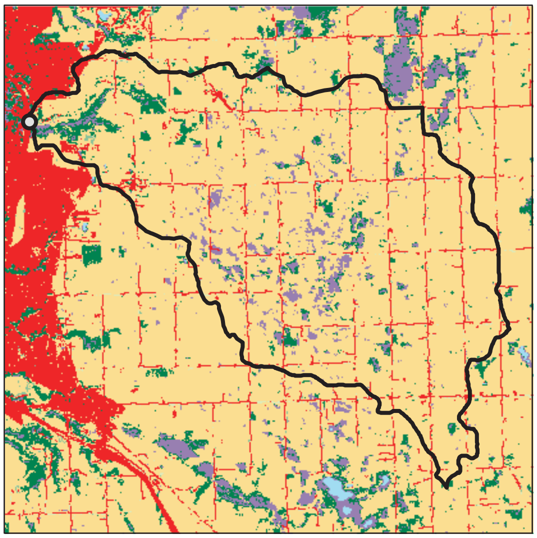
Sampling site

Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

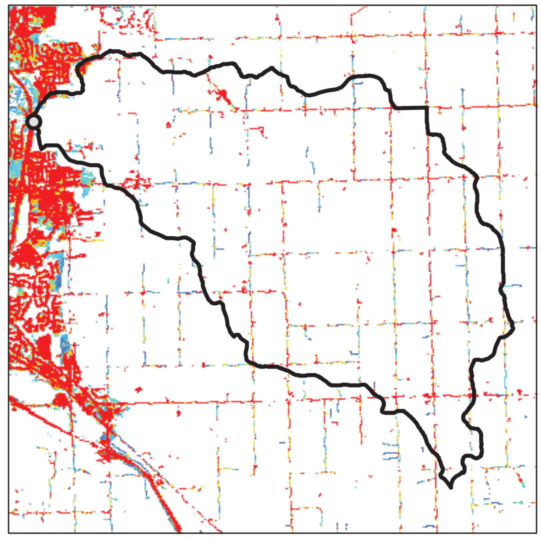
Baird Creek at Superior Rd. near Green Bay, Wis.

(BAIR; site 9; urban intensity index value = 19.20)

A. 2001 Land cover (developed land = 5.48 percent)



B. Impervious surface (mean = 1.56 percent)



EXPLANATION

2001 Land cover

- Open water
- Developed
- Barren
- Forest
- Shrub/scrub
- Grassland/herbaceous
- Cultivated crops/pasture
- Wetlands
- Study watershed boundary
- Sampling site

EXPLANATION

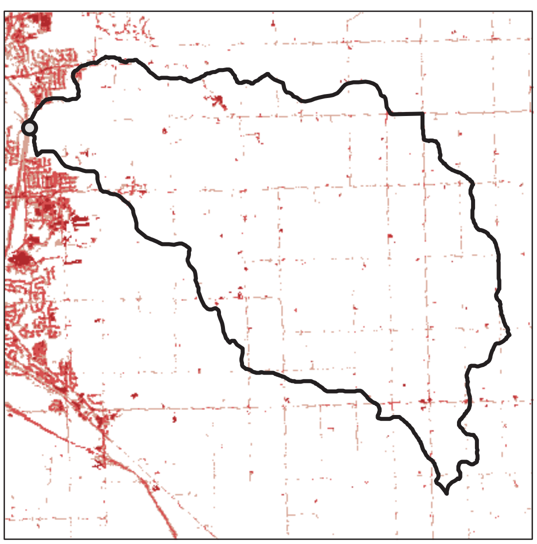
2001 Impervious surface, in percent

High : 100

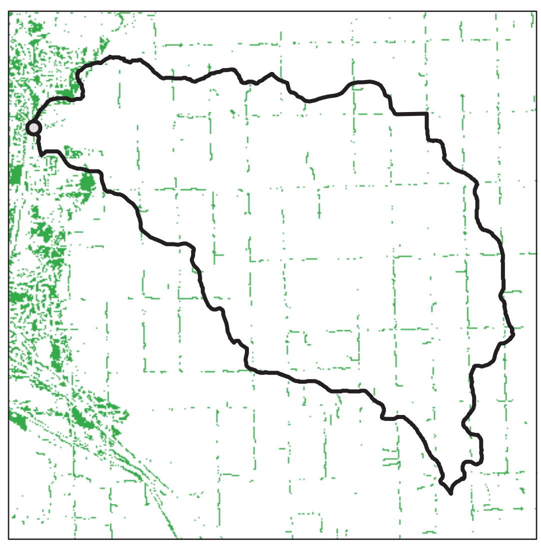
Low : 0

- Study watershed boundary
- Sampling site

C. Developed land (low, medium and high intensity = 3.09 percent)



D. Developed land (open space = 2.44 percent)



EXPLANATION

2001 Land cover

- Developed, low density
- Developed, medium density
- Developed, high density
- Study watershed boundary
- Sampling site

0 1 2 MILES

0 1 2 KILOMETERS

EXPLANATION

2001 Land cover

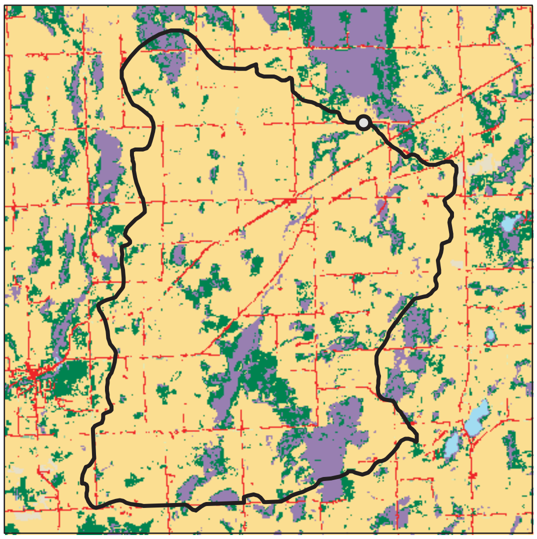
- Developed, open space
- Study watershed boundary
- Sampling site

Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

Rio Creek at Pheasant Road near Rio Creek, Wis.

(RIOC; site 10; urban intensity index value = 10.48)

A. 2001 Land cover (developed land = 3.53 percent)

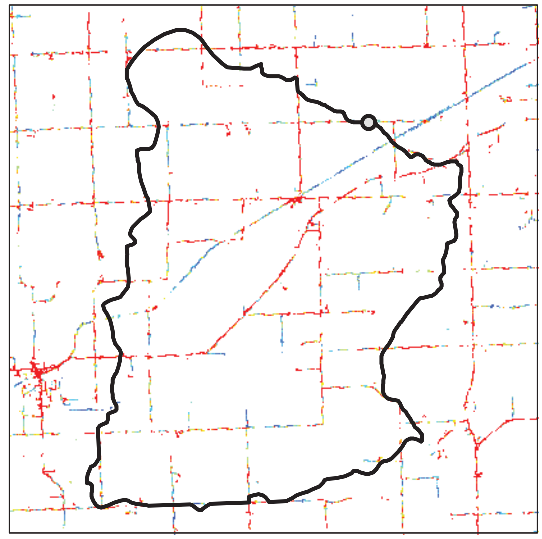


EXPLANATION

2001 Land cover

Open water
Developed
Barren
Forest
Shrub/scrub
Grassland/herbaceous
Cultivated crops/pasture
Wetlands
Study watershed boundary
Sampling site

B. Impervious surface (mean = 0.89 percent)



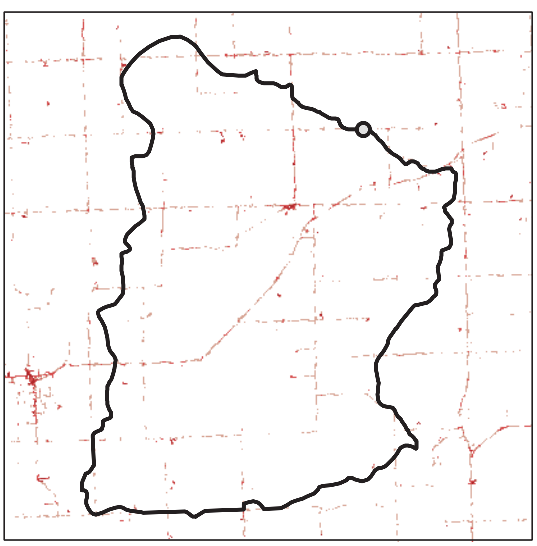
EXPLANATION

2001 Impervious surface, in percent

High : 100
Low : 0

Study watershed boundary
Sampling site

C. Developed land (low, medium and high intensity = 1.90 percent)

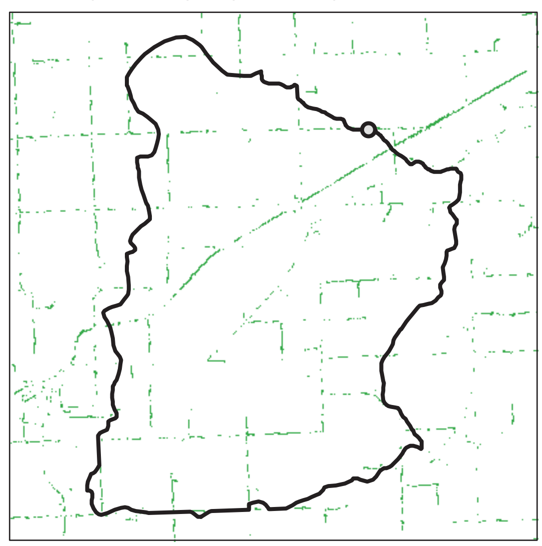


EXPLANATION

2001 Land cover

Developed, low density
Developed, medium density
Developed, high density
Study watershed boundary
Sampling site

D. Developed land (open space = 1.67 percent)



EXPLANATION

2001 Land cover

Developed, open space
Study watershed boundary
Sampling site

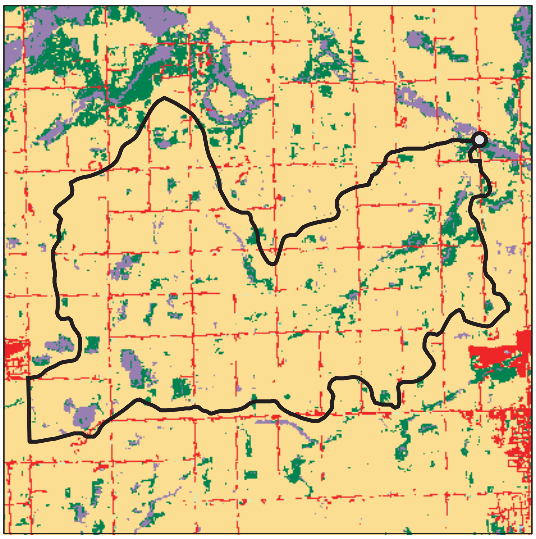
0 2 4 MILES
0 2 4 KILOMETERS

Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

Kewaunee River Tributary at Lowell Rd. near Luxemburg, Wis.

(KEWA; site 11; urban intensity index value = 13.78)

A. 2001 Land cover (developed land = 4.37 percent)

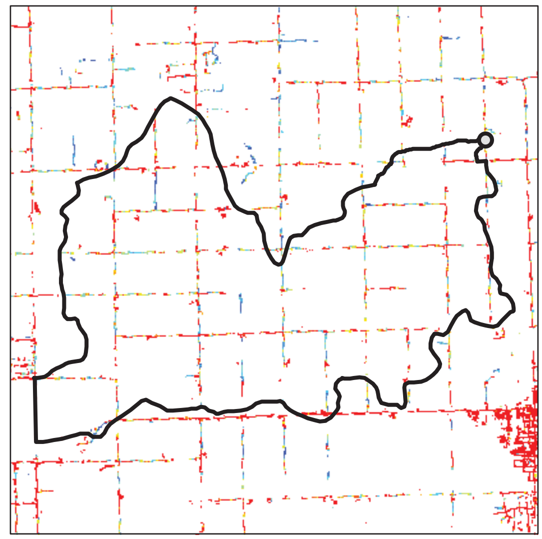


EXPLANATION

2001 Land cover

- Open water
- Developed
- Barren
- Forest
- Shrub/scrub
- Grassland/herbaceous
- Cultivated crops/pasture
- Wetlands
- Study watershed boundary
- Sampling site

B. Impervious surface (mean = 1.10 percent)



EXPLANATION

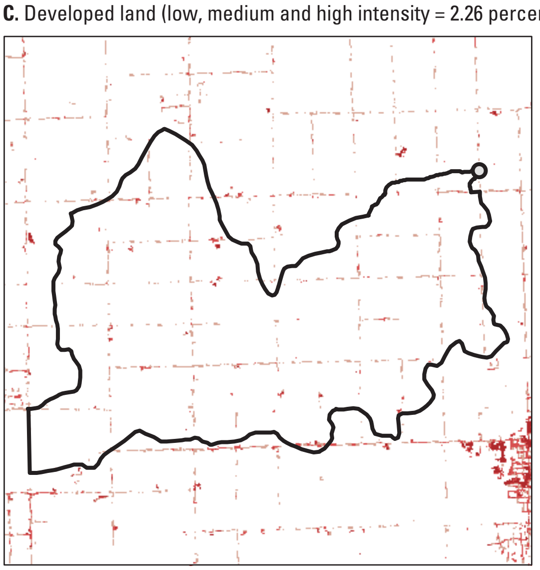
2001 Impervious surface, in percent

High : 100

Low : 0

- Study watershed boundary
- Sampling site

C. Developed land (low, medium and high intensity = 2.26 percent)

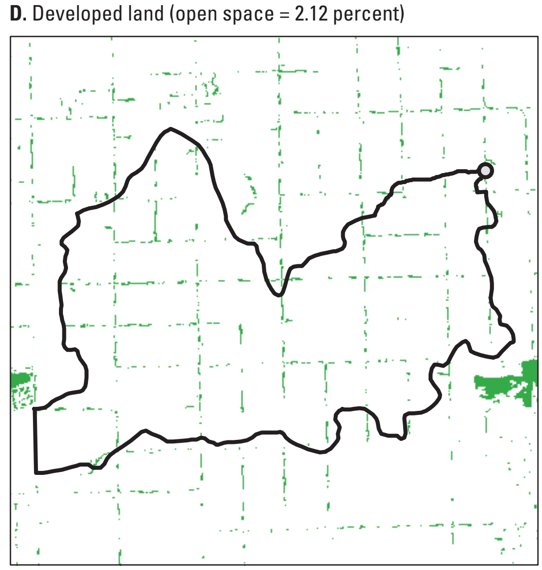


EXPLANATION

2001 Land cover

- Developed, low density
- Developed, medium density
- Developed, high density
- Study watershed boundary
- Sampling site

D. Developed land (open space = 2.12 percent)



EXPLANATION

2001 Land cover

- Developed, open space
- Study watershed boundary
- Sampling site

0 1 2 MILES

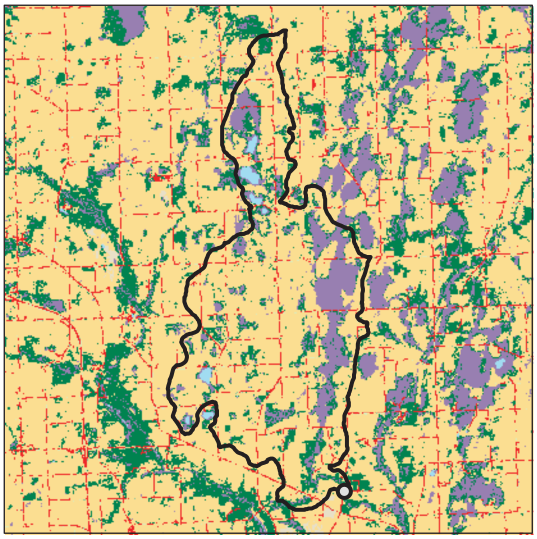
0 1 2 KILOMETERS

Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

Jambo Creek at Jambo Creek Rd. near Mishicot, Wis.

(JAMB; site 12; urban intensity index value = 0.00)

A. 2001 Land cover (developed land = 3.71 percent)

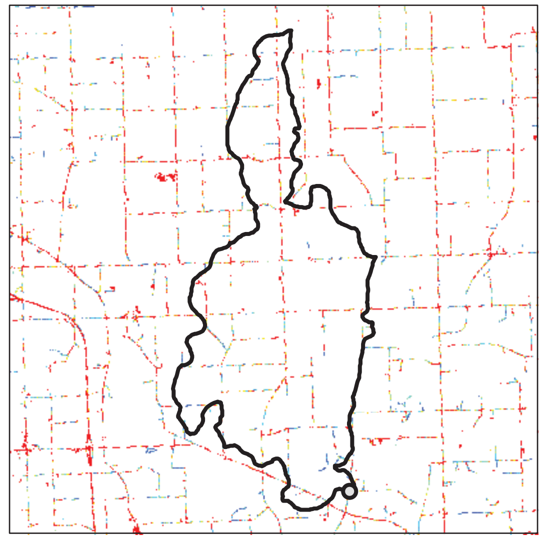


EXPLANATION

2001 Land cover

- Open water
- Developed
- Barren
- Forest
- Shrub/scrub
- Grassland/herbaceous
- Cultivated crops/pasture
- Wetlands
- Study watershed boundary
- Sampling site

B. Impervious surface (mean = 0.94 percent)



EXPLANATION

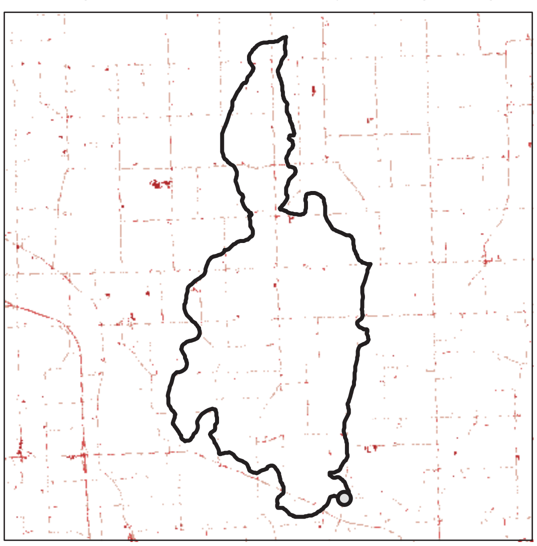
2001 Impervious surface, in percent

High : 100

Low : 0

- Study watershed boundary
- Sampling site

C. Developed land (low, medium and high intensity = 1.96 percent)

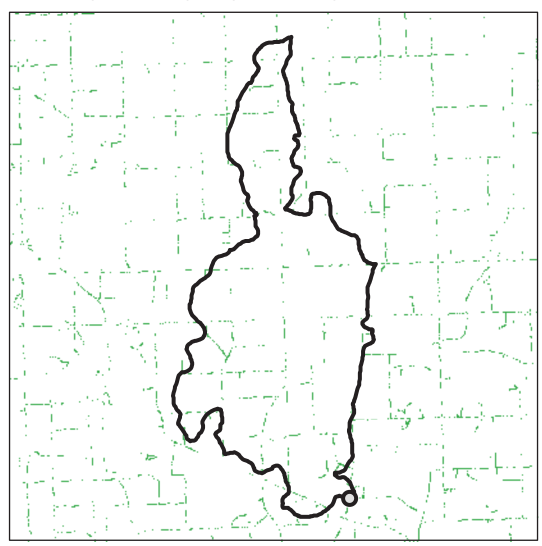


EXPLANATION

2001 Land cover

- Developed, low density
- Developed, medium density
- Developed, high density
- Study watershed boundary
- Sampling site

D. Developed land (open space = 1.80 percent)



EXPLANATION

2001 Land cover

- Developed, open space
- Study watershed boundary
- Sampling site

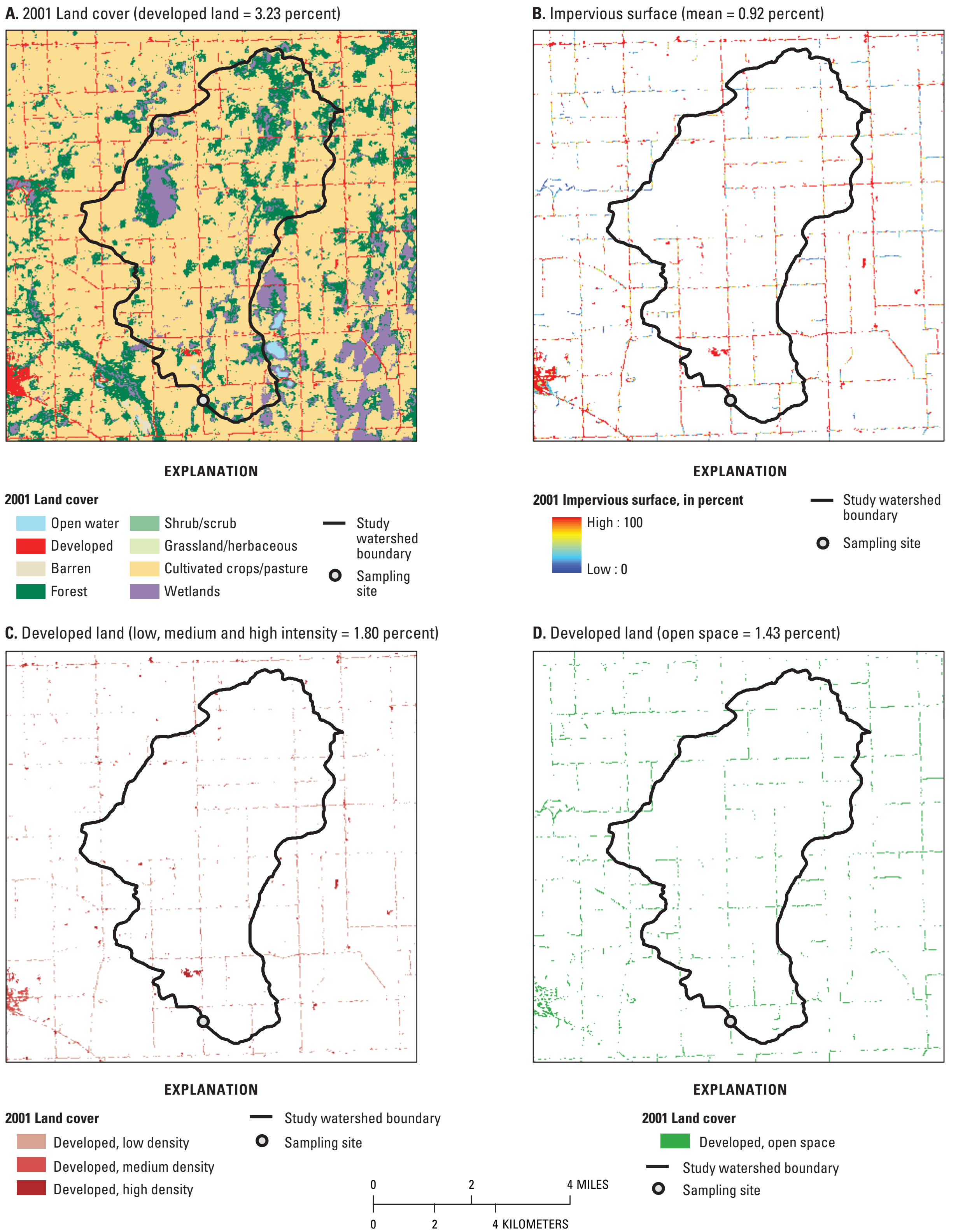
0 2.5 5 MILES

0 2.5 5 KILOMETERS

Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

Black Creek at Curran Rd. near Denmark, Wis.

(BLAK; site 13; urban intensity index value = 4.18)

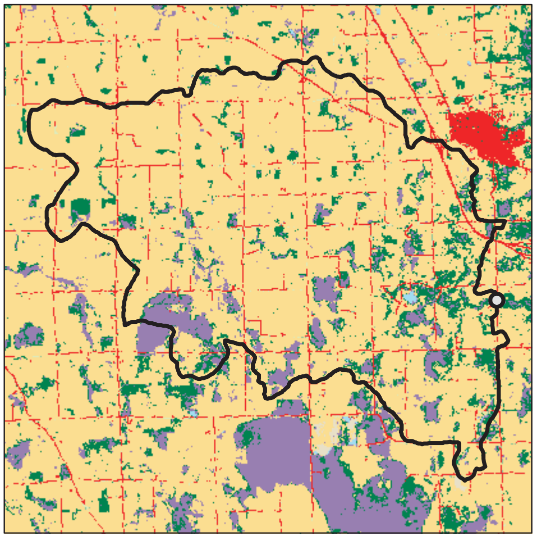


Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

Devils River at Rosencrans Rd. near Mishicot, Wis.

(DEVL; site 14; urban intensity index value = 10.81)

A. 2001 Land cover (developed land = 4.00 percent)

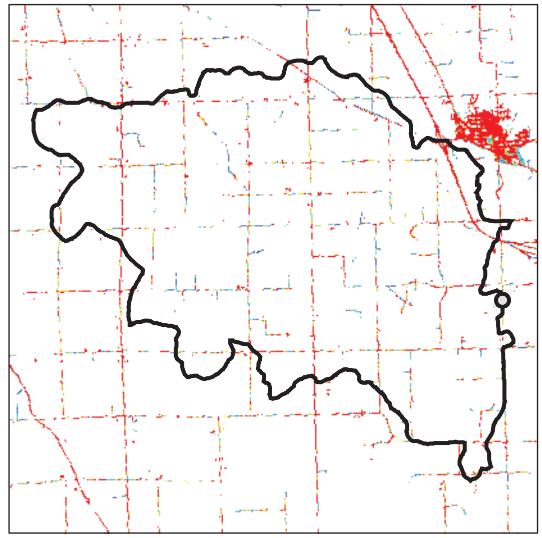


EXPLANATION

2001 Land cover

- Open water
- Developed
- Barren
- Forest
- Shrub/scrub
- Grassland/herbaceous
- Cultivated crops/pasture
- Wetlands
- Study watershed boundary
- Sampling site

B. Impervious surface (mean = 1.01 percent)



EXPLANATION

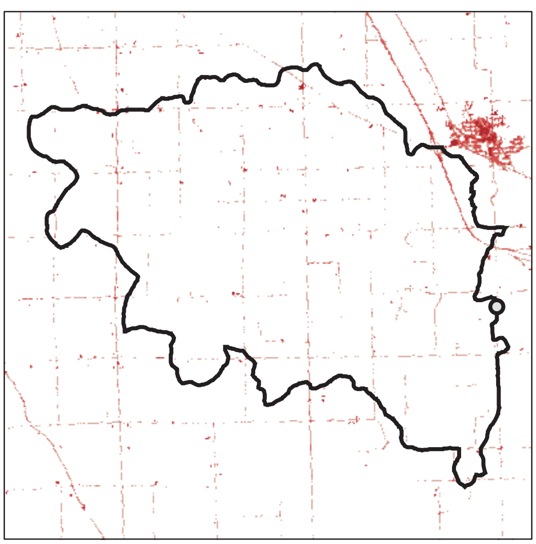
2001 Impervious surface, in percent

High : 100

Low : 0

- Study watershed boundary
- Sampling site

C. Developed land (low, medium and high intensity = 2.07 percent)

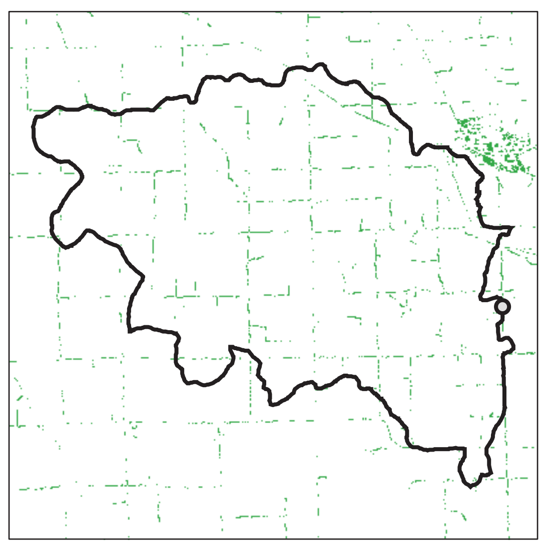


EXPLANATION

2001 Land cover

- Developed, low density
- Developed, medium density
- Developed, high density
- Study watershed boundary
- Sampling site

D. Developed land (open space = 1.93 percent)



EXPLANATION

2001 Land cover

- Developed, open space
- Study watershed boundary
- Sampling site

0 2 4 MILES

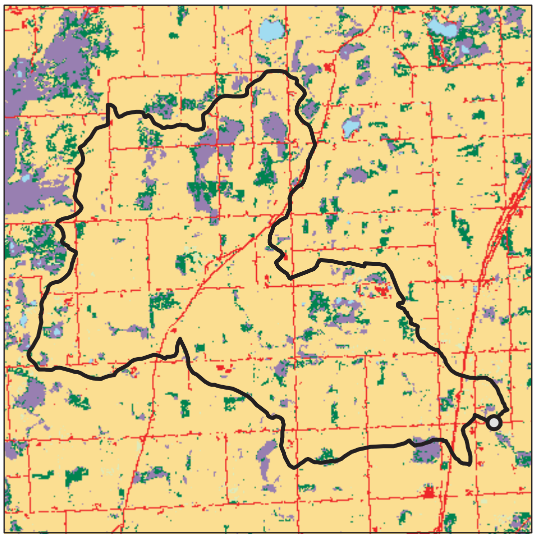
0 2 4 KILOMETERS

Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

Point Creek at Ucker Rd. near Newton, Wis.

(POIN; site 15; urban intensity index value = 19.50)

A. 2001 Land cover (developed land = 5.02 percent)

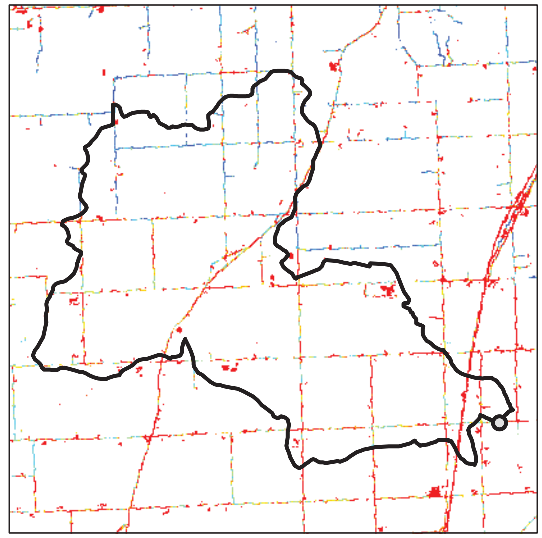


EXPLANATION

2001 Land cover

- Open water
- Developed
- Barren
- Forest
- Shrub/scrub
- Grassland/herbaceous
- Cultivated crops/pasture
- Wetlands
- Study watershed boundary
- Sampling site

B. Impervious surface (mean =1.42 percent)



EXPLANATION

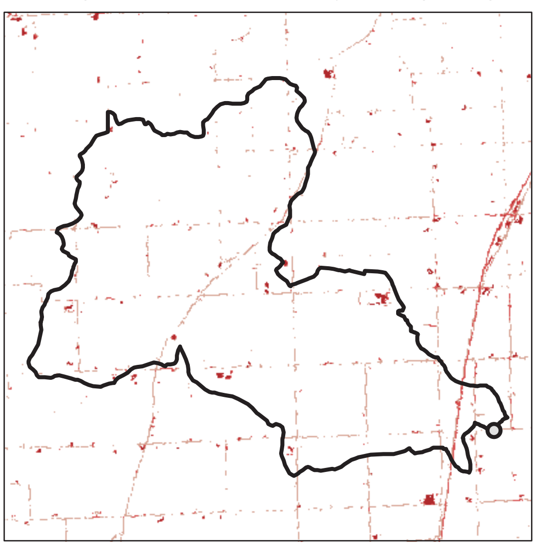
2001 Impervious surface, in percent

High : 100

Low : 0

- Study watershed boundary
- Sampling site

C. Developed land (low, medium and high intensity = 2.82 percent)



EXPLANATION

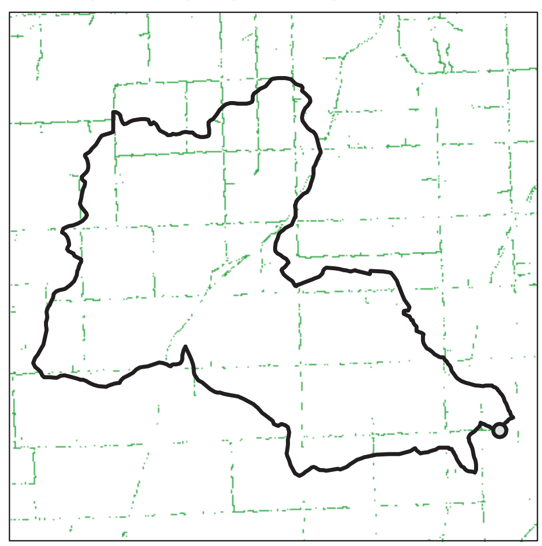
2001 Land cover

- Developed, low density
- Developed, medium density
- Developed, high density
- Study watershed boundary
- Sampling site

0 2 4 MILES

0 2 4 KILOMETERS

D. Developed land (open space = 2.20 percent)



EXPLANATION

2001 Land cover

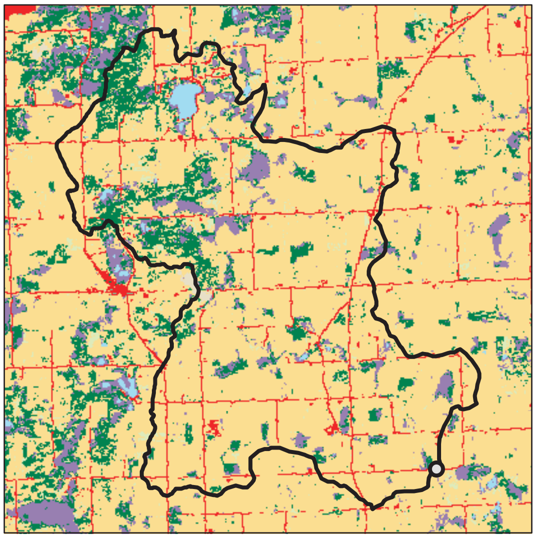
- Developed, open space
- Study watershed boundary
- Sampling site

Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

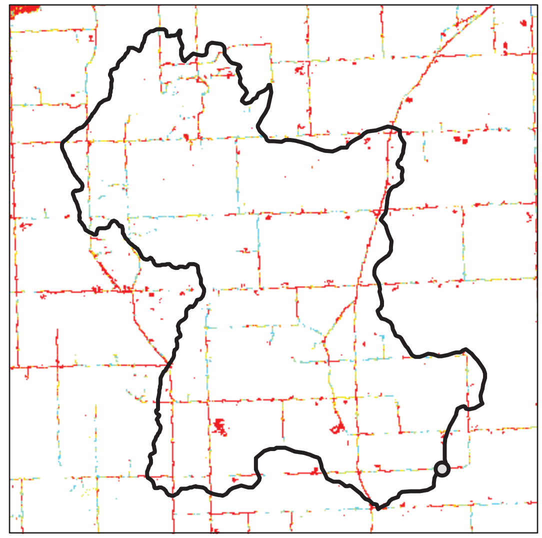
Meeme River at Washington Rd. near Cleveland, Wis.

(MEME; site 16; urban intensity index value = 6.96)

A. 2001 Land cover (developed land = 5.04 percent)



B. Impervious surface (mean = 1.43 percent)



EXPLANATION

2001 Land cover

- Open water
- Developed
- Barren
- Forest
- Shrub/scrub
- Grassland/herbaceous
- Cultivated crops/pasture
- Wetlands
- Study watershed boundary
- Sampling site

EXPLANATION

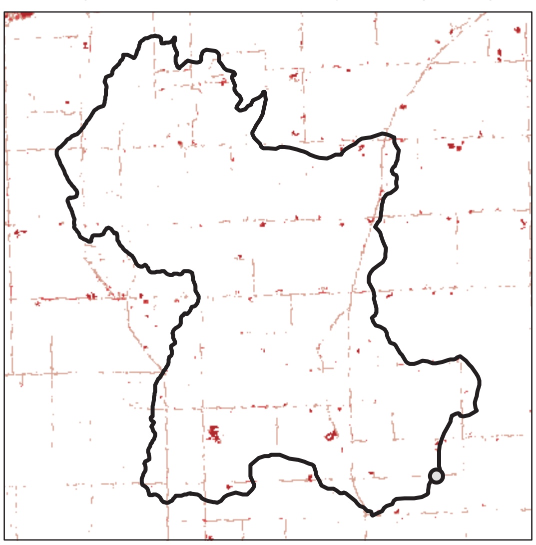
2001 Impervious surface, in percent

High : 100

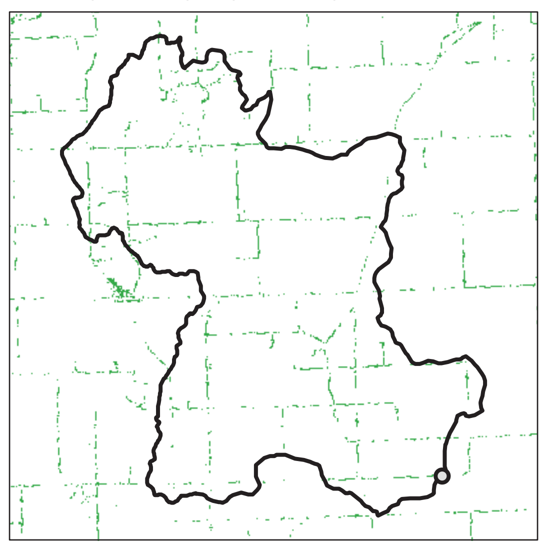
Low : 0

- Study watershed boundary
- Sampling site

C. Developed land (low, medium and high intensity = 2.88 percent)



D. Developed land (open space = 2.16 percent)



EXPLANATION

2001 Land cover

- Developed, low density
- Developed, medium density
- Developed, high density
- Study watershed boundary
- Sampling site

EXPLANATION

2001 Land cover

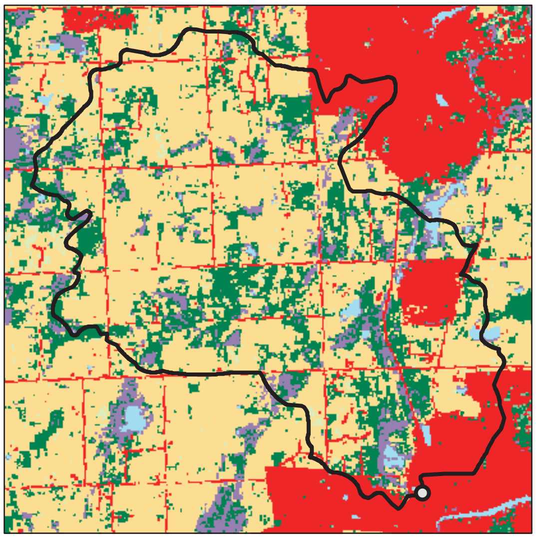
- Developed, open space
- Study watershed boundary
- Sampling site

Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

Pigeon Creek at Williamsburg Dr. at Theinsville, Wis.

(PIGN; site 17; urban intensity index value = 51.83)

A. 2001 Land cover (developed land = 14.92 percent)

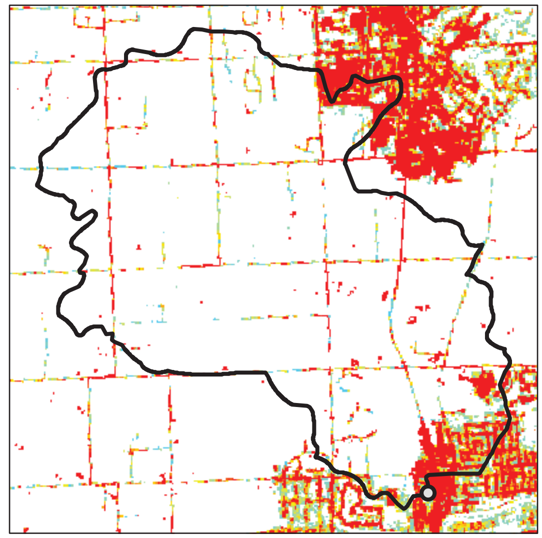


EXPLANATION

2001 Land cover

- Open water
- Developed
- Barren
- Forest
- Shrub/scrub
- Grassland/herbaceous
- Cultivated crops/pasture
- Wetlands
- Study watershed boundary
- Sampling site

B. Impervious surface (mean = 3.54 percent)



EXPLANATION

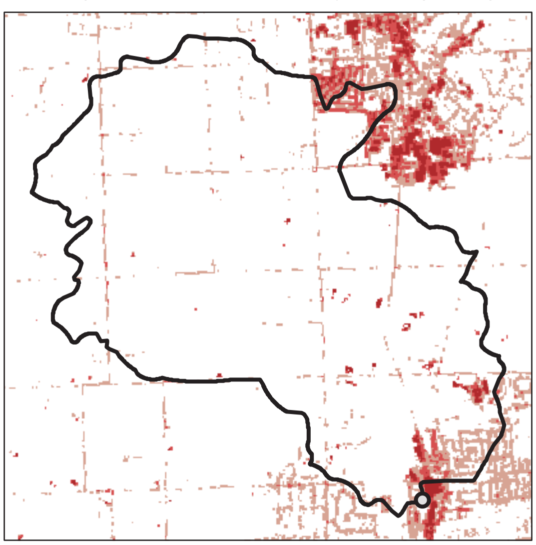
2001 Impervious surface, in percent

High : 100

Low : 0

- Study watershed boundary
- Sampling site

C. Developed land (low, medium and high intensity = 6.85 percent)

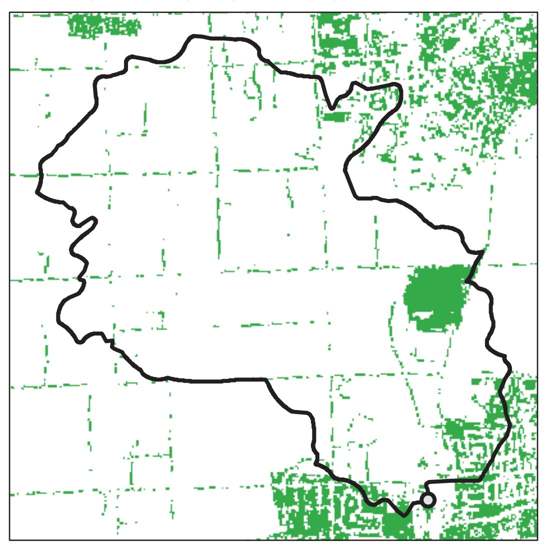


EXPLANATION

2001 Land cover

- Developed, low density
- Developed, medium density
- Developed, high density
- Study watershed boundary
- Sampling site

D. Developed land (open space = 8.07 percent)



EXPLANATION

2001 Land cover

- Developed, open space
- Study watershed boundary
- Sampling site

0 1 2 MILES

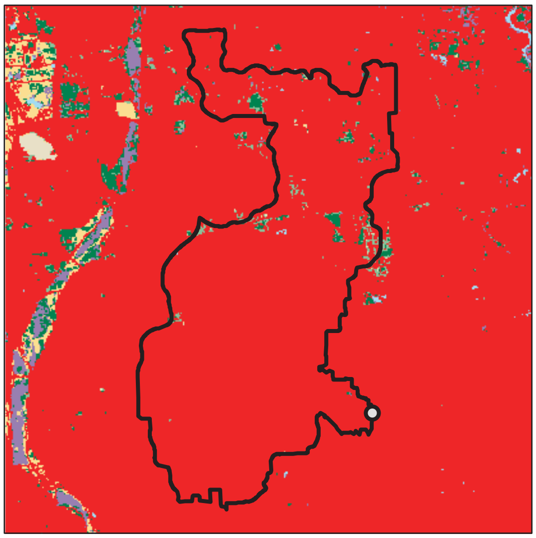
0 1 2 KILOMETERS

Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

Lincoln Creek at 47th St. at Milwaukee, Wis.

(LINC; site 18; urban intensity index value = 100.00)

A. 2001 Land cover (developed land = 97.56 percent)

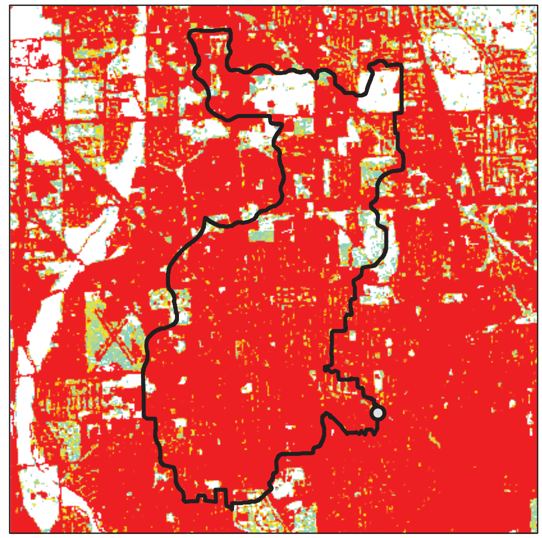


EXPLANATION

2001 Land cover

- Open water
- Developed
- Barren
- Forest
- Shrub/scrub
- Grassland/herbaceous
- Cultivated crops/pasture
- Wetlands
- Study watershed boundary
- Sampling site

B. Impervious surface (mean = 44.61 percent)



EXPLANATION

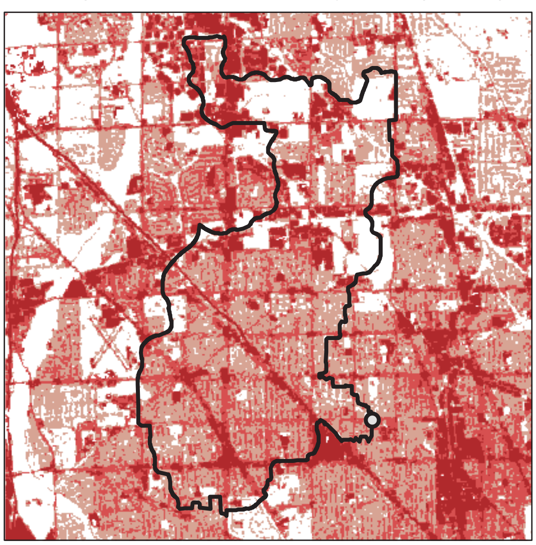
2001 Impervious surface, in percent

High : 100

Low : 0

- Study watershed boundary
- Sampling site

C. Developed land (low, medium and high intensity = 80.50 percent)

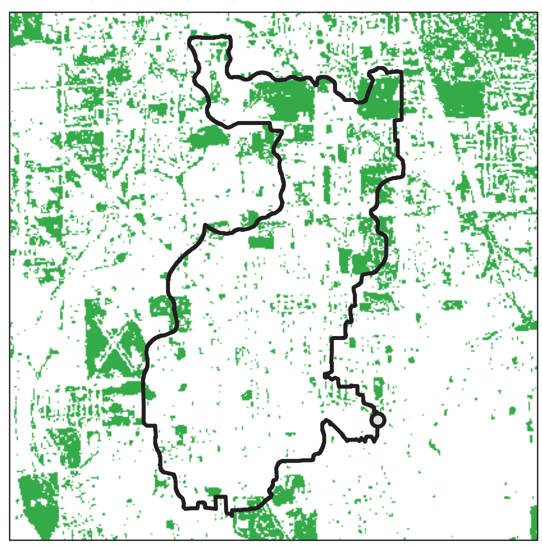


EXPLANATION

2001 Land cover

- Developed, low density
- Developed, medium density
- Developed, high density
- Study watershed boundary
- Sampling site

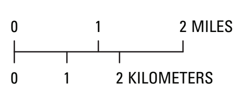
D. Developed land (open space = 17.06 percent)



EXPLANATION

2001 Land cover

- Developed, open space
- Study watershed boundary
- Sampling site

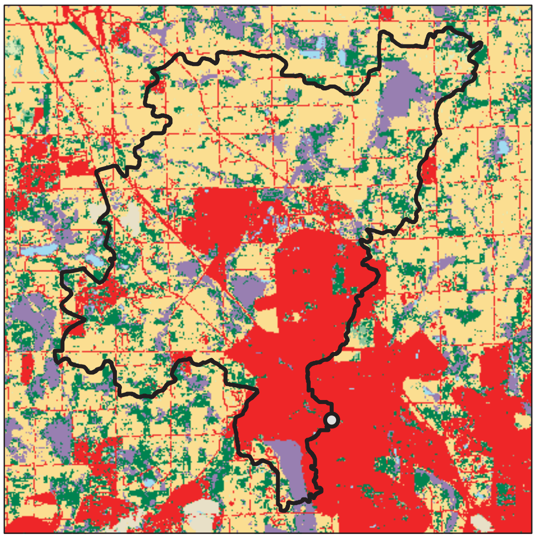


Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

Menomonee River at Menomonee Falls, Wis.

(MENO; site 19; urban intensity index value = 49.47)

A. 2001 Land cover (developed land = 30.39 percent)

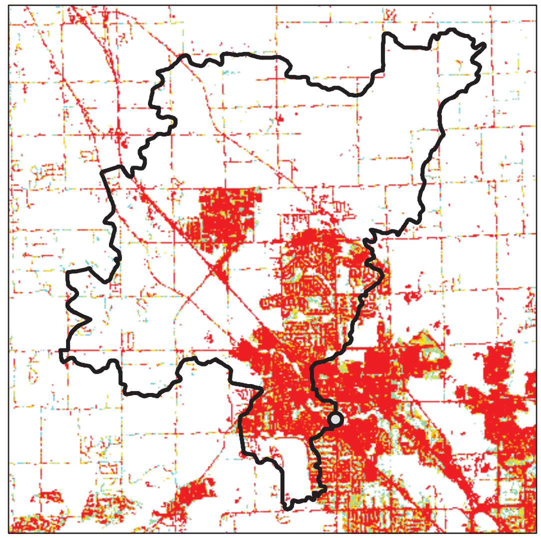


EXPLANATION

2001 Land cover

- Open water
- Developed
- Barren
- Forest
- Shrub/scrub
- Grassland/herbaceous
- Cultivated crops/pasture
- Wetlands
- Study watershed boundary
- Sampling site

B. Impervious surface (mean = 10.46 percent)



EXPLANATION

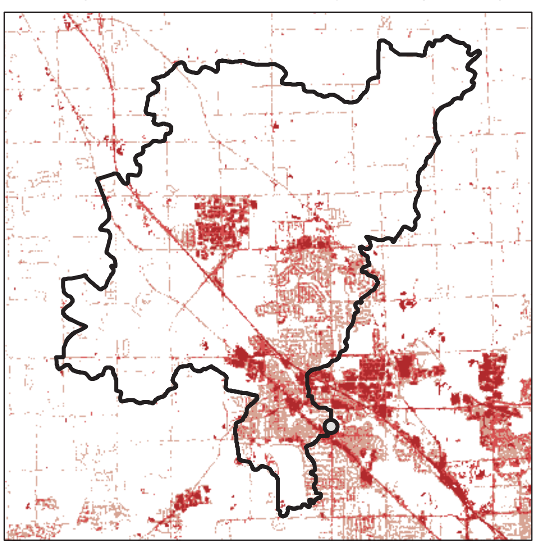
2001 Impervious surface, in percent

High : 100

Low : 0

- Study watershed boundary
- Sampling site

C. Developed land (low, medium and high intensity = 19.78 percent)

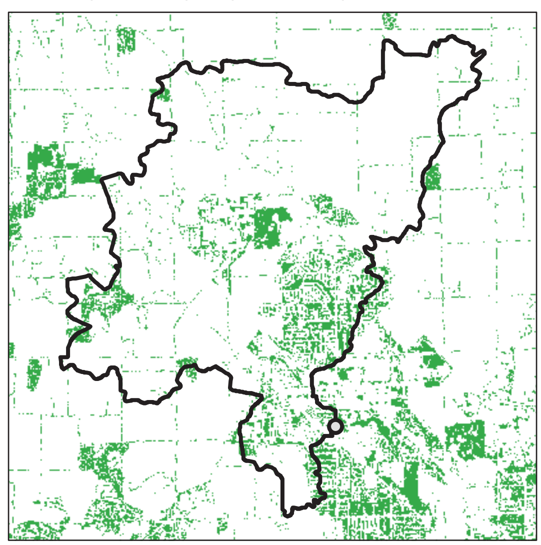


EXPLANATION

2001 Land cover

- Developed, low density
- Developed, medium density
- Developed, high density
- Study watershed boundary
- Sampling site

D. Developed land (open space = 10.61 percent)



EXPLANATION

2001 Land cover

- Developed, open space
- Study watershed boundary
- Sampling site

0 2.5 5 MILES

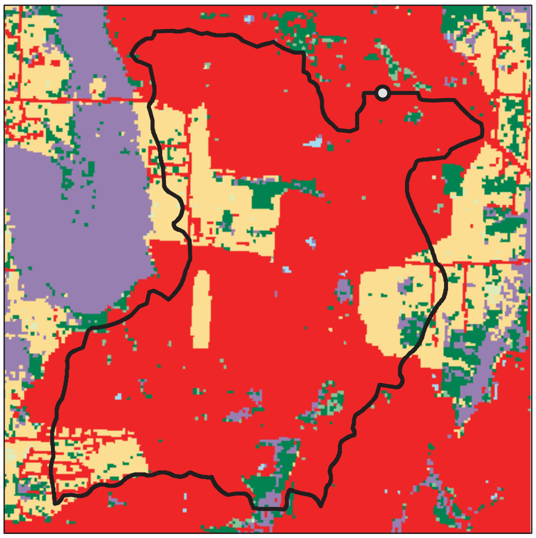
0 2.5 5 KILOMETERS

Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

Lily Creek at Good Hope Rd. near Menomonee Falls, Wis.

(LILY; site 20; urban intensity index value = 60.29)

A. 2001 Land cover (developed land = 77.99 percent)

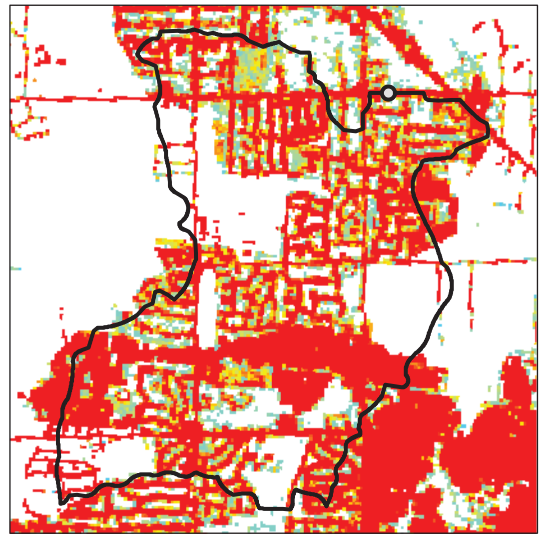


EXPLANATION

2001 Land cover

- Open water
- Developed
- Barren
- Forest
- Shrub/scrub
- Grassland/herbaceous
- Cultivated crops/pasture
- Wetlands
- Study watershed boundary
- Sampling site

B. Impervious surface (mean = 24.95 percent)



EXPLANATION

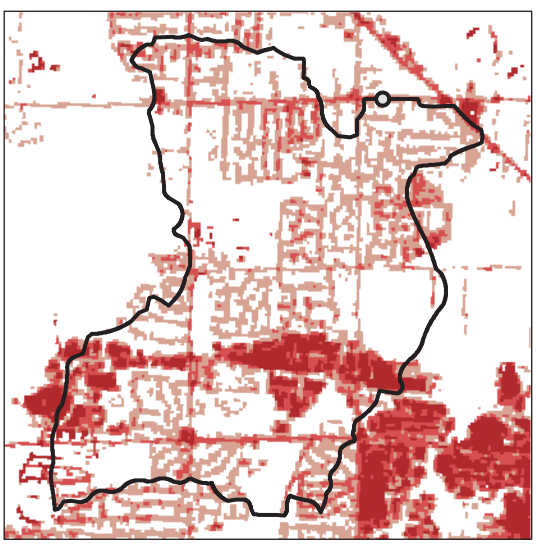
2001 Impervious surface, in percent

High : 100

Low : 0

- Study watershed boundary
- Sampling site

C. Developed land (low, medium and high intensity = 47.07 percent)

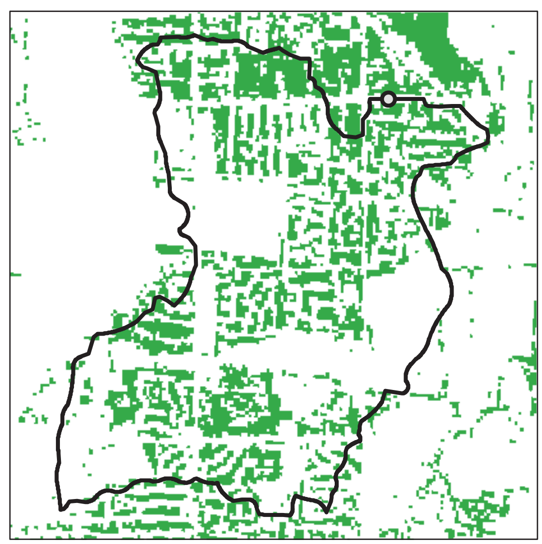


EXPLANATION

2001 Land cover

- Developed, low density
- Developed, medium density
- Developed, high density
- Study watershed boundary
- Sampling site

D. Developed land (open space = 30.69 percent)



EXPLANATION

2001 Land cover

- Developed, open space
- Study watershed boundary
- Sampling site

0 0.5 1 MILE

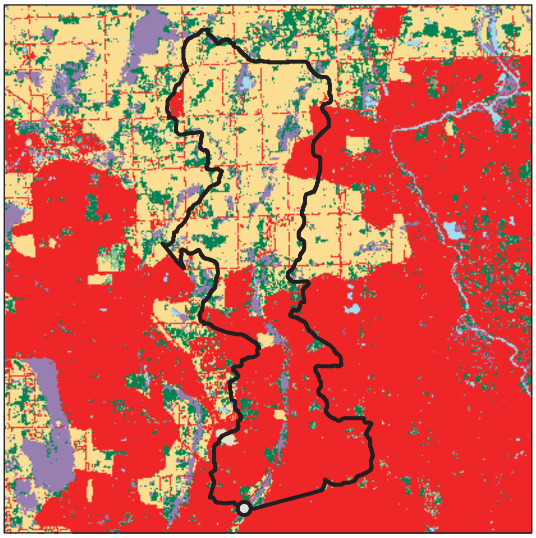
0 0.5 1 KILOMETER

Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

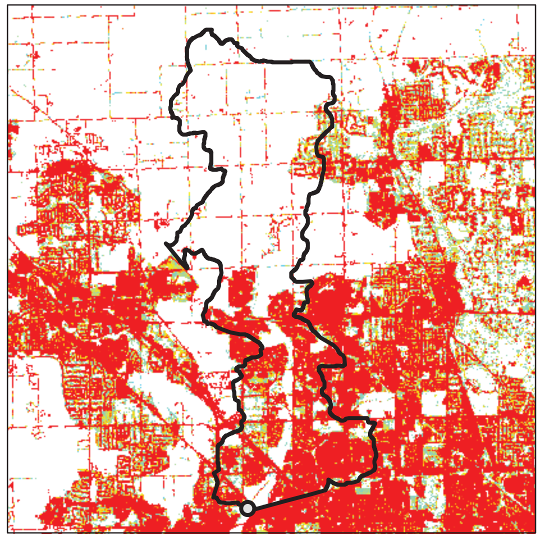
Little Menomonee River at Milwaukee, Wis.

(LTME; site 21; urban intensity index value = 71.54)

A. 2001 Land cover (developed land = 44.28 percent)



B. Impervious surface (mean = 18.80 percent)



EXPLANATION

2001 Land cover

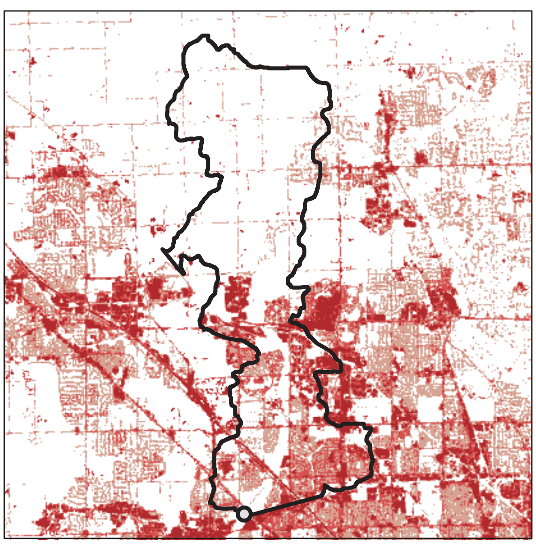
- Open water
- Developed
- Barren
- Forest
- Shrub/scrub
- Grassland/herbaceous
- Cultivated crops/pasture
- Wetlands
- Study watershed boundary
- Sampling site

EXPLANATION

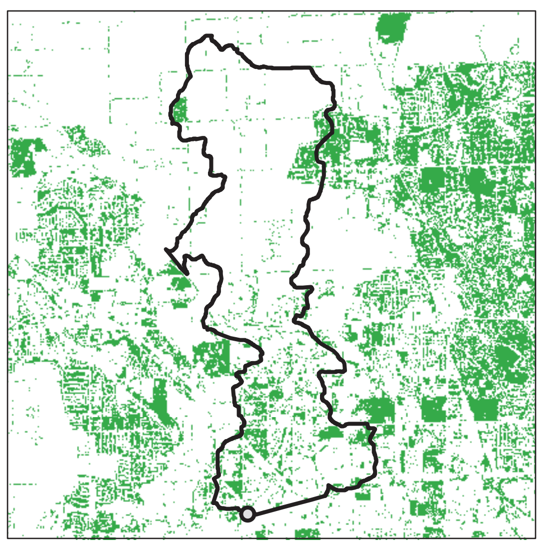
2001 Impervious surface, in percent

- High : 100
- Low : 0
- Study watershed boundary
- Sampling site

C. Developed land (low, medium and high intensity = 31.81 percent)



D. Developed land (open space = 12.47 percent)



EXPLANATION

2001 Land cover

- Developed, low density
- Developed, medium density
- Developed, high density
- Study watershed boundary
- Sampling site

0 2 4 MILES

0 2 4 KILOMETERS

EXPLANATION

2001 Land cover

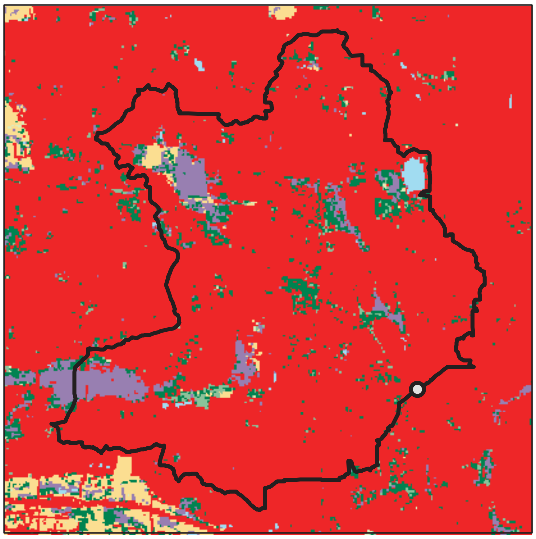
- Developed, open space
- Study watershed boundary
- Sampling site

Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

Underwood Creek at Watertown Plank Rd. at Elm Grove, Wis.

(UNDW; site 22; urban intensity index value = 74.82)

A. 2001 Land cover (developed land = 86.05 percent)

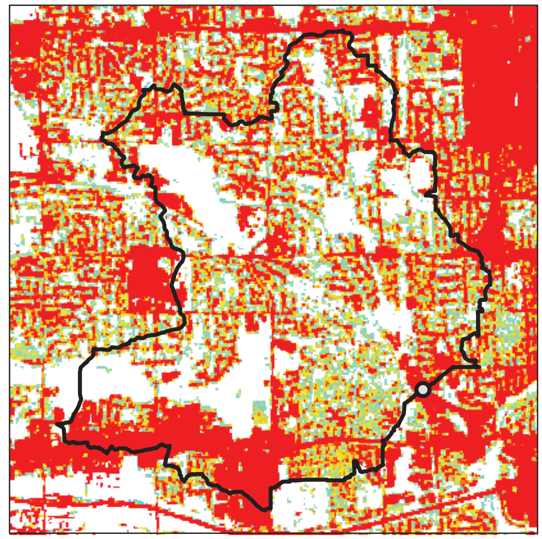


EXPLANATION

2001 Land cover

Open water
Developed
Barren
Forest
Shrub/scrub
Grassland/herbaceous
Cultivated crops/pasture
Wetlands
Study watershed boundary
Sampling site

B. Impervious surface (mean = 19.96 percent)



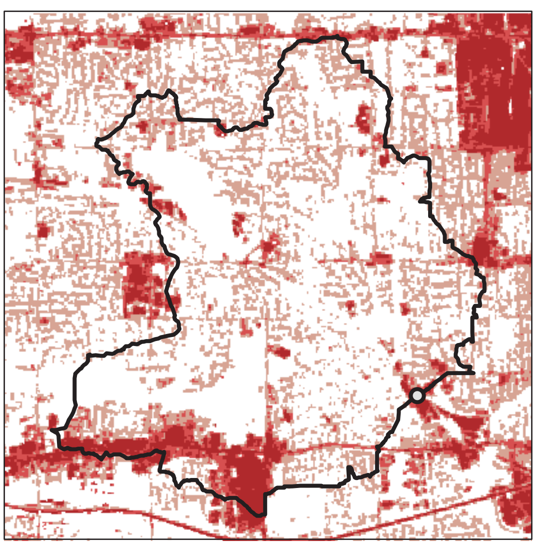
EXPLANATION

2001 Impervious surface, in percent

High : 100
Low : 0

Study watershed boundary
Sampling site

C. Developed land (low, medium and high intensity = 35.96 percent)

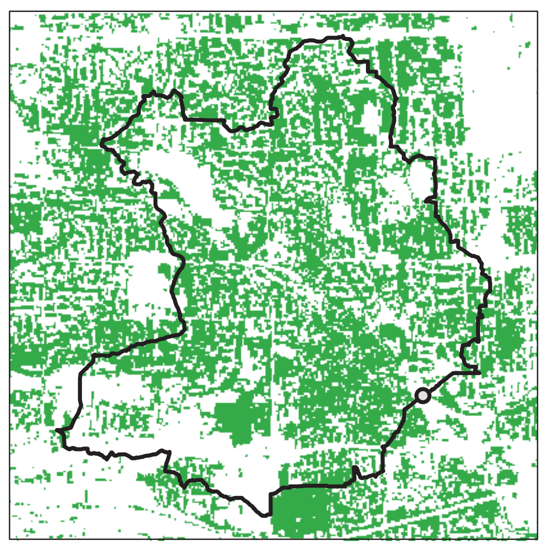


EXPLANATION

2001 Land cover

Developed, low density
Developed, medium density
Developed, high density
Study watershed boundary
Sampling site

D. Developed land (open space = 50.19 percent)



EXPLANATION

2001 Land cover

Developed, open space
Study watershed boundary
Sampling site

0 1 2 MILES
0 1 2 KILOMETERS

Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

Honey Creek near Portland Ave. at Wauwatosa, Wis.

(HONY; site 23; urban intensity index value = 85.24)

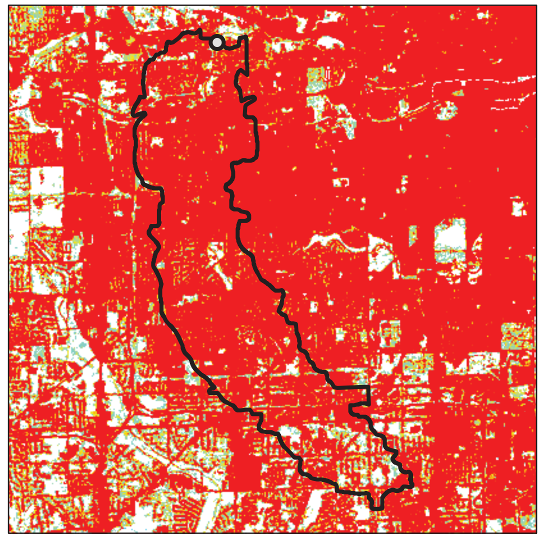
A. 2001 Land cover (developed land = 99.06 percent)

EXPLANATION

2001 Land cover

Open water
Developed
Barren
Forest
Shrub/scrub
Grassland/herbaceous
Cultivated crops/pasture
Wetlands
Study watershed boundary
Sampling site

B. Impervious surface (mean = 47.58 percent)

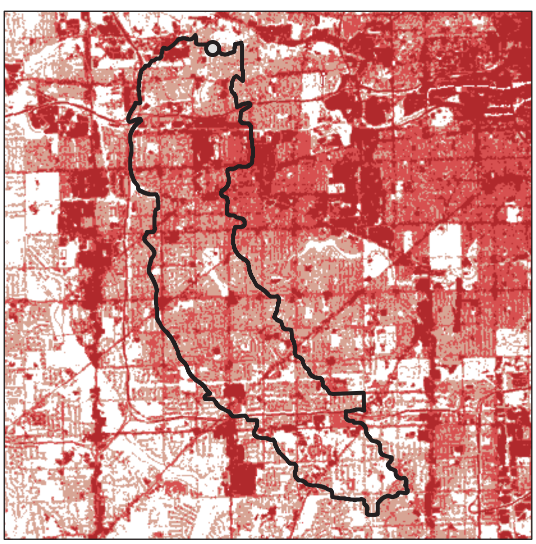


EXPLANATION

2001 Impervious surface, in percent

High : 100
Low : 0
Study watershed boundary
Sampling site

C. Developed land (low, medium and high intensity = 85.24 percent)

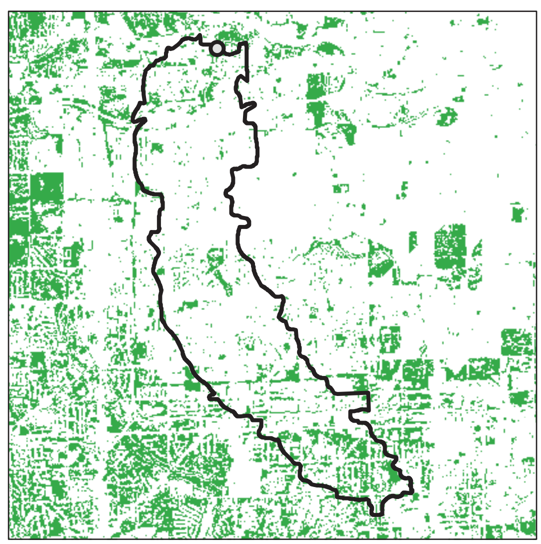


EXPLANATION

2001 Land cover

Developed, low density
Developed, medium density
Developed, high density
Study watershed boundary
Sampling site

D. Developed land (open space = 13.82 percent)



EXPLANATION

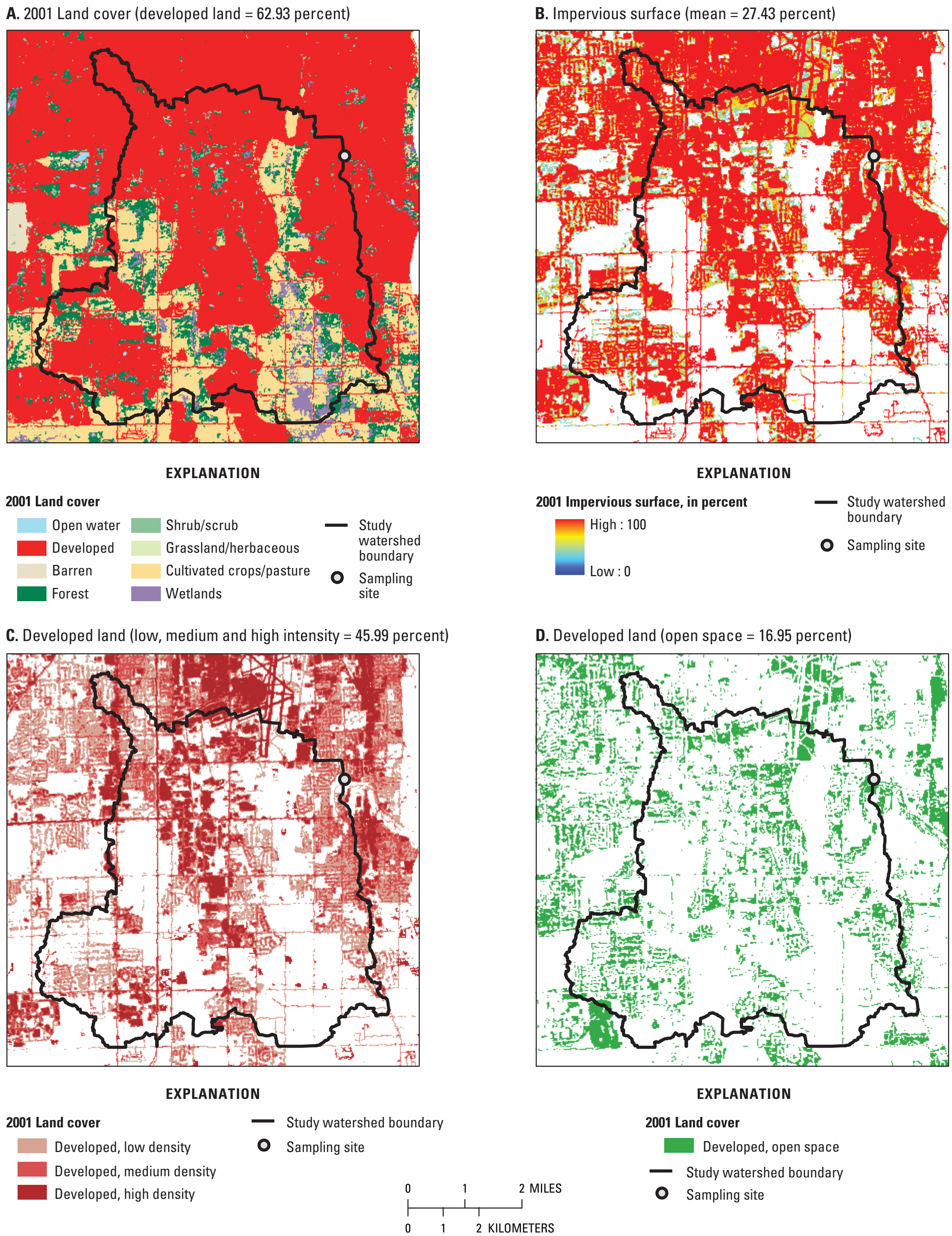
2001 Land cover

Developed, open space
Study watershed boundary
Sampling site

Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

Oak Creek at South Milwaukee, Wis.

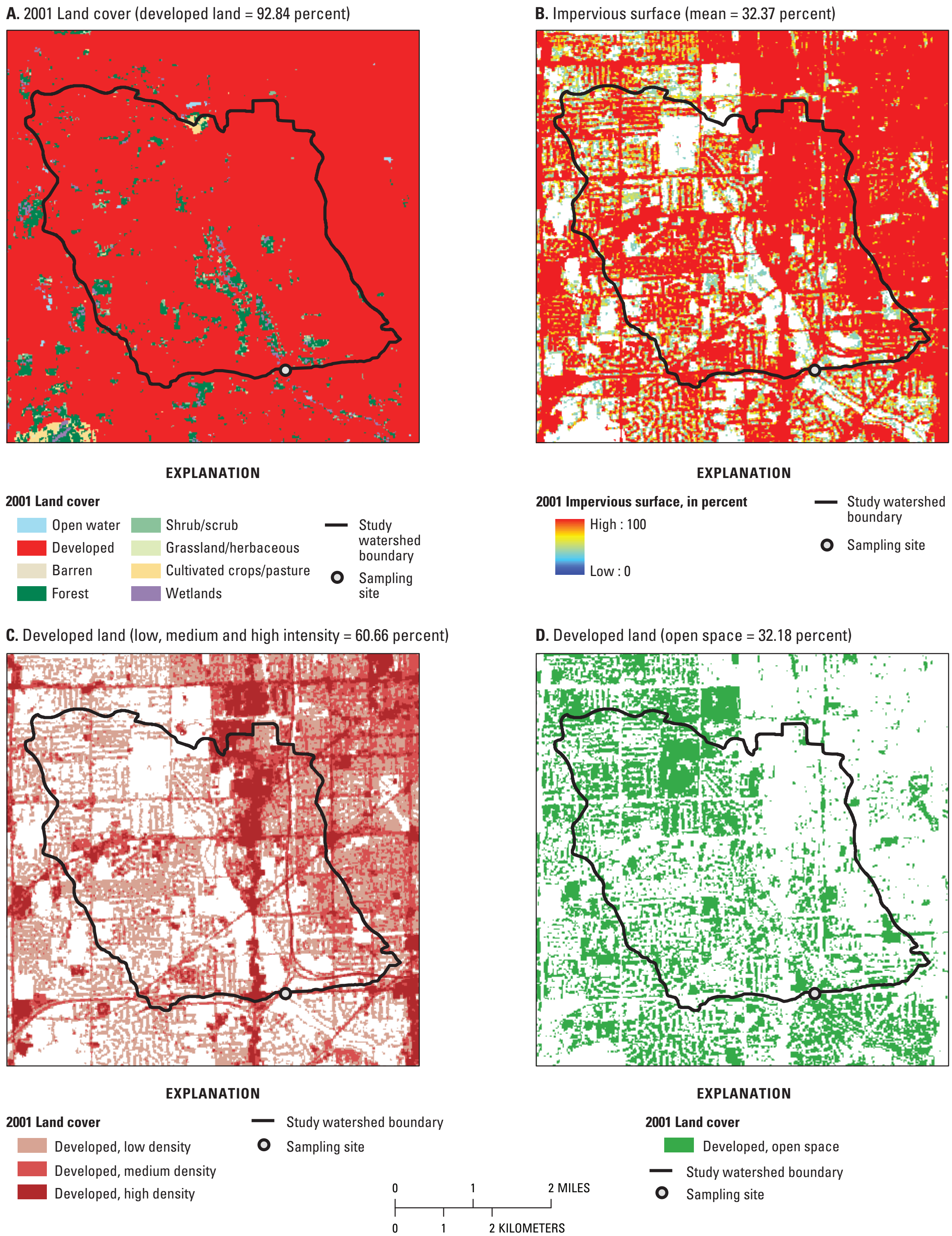
(OAKC; site 24; urban intensity index value = 76.37)



Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

Root River at Layton Ave. at Greenfield, Wis.

(ROOT; site 25; urban intensity index value = 89.25)

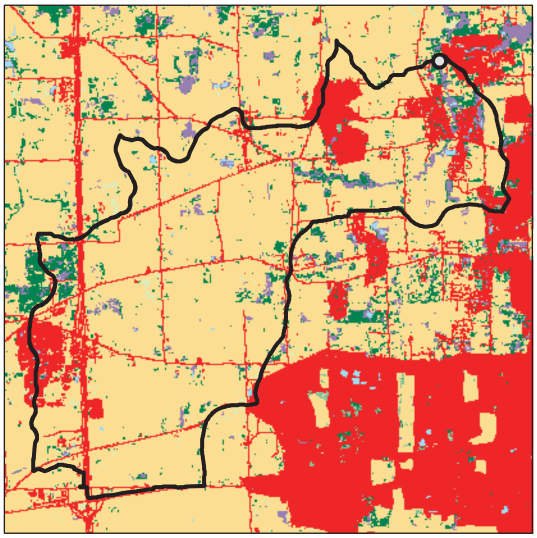


Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

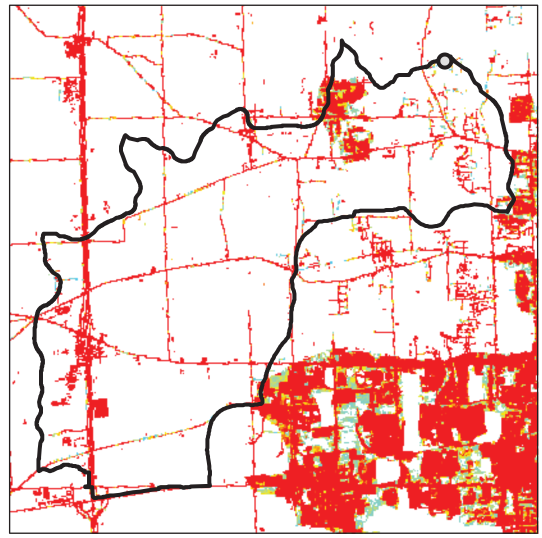
Hoods Creek at Brook Rd. near Franksville, Wis.

(HOOD; site 26; urban intensity index value = 31.26)

A. 2001 Land cover (developed land = 16.30 percent)



B. Impervious surface (mean = 5.98 percent)



EXPLANATION

2001 Land cover

- Open water
- Developed
- Barren
- Forest
- Shrub/scrub
- Grassland/herbaceous
- Cultivated crops/pasture
- Wetlands
- Study watershed boundary
- Sampling site

EXPLANATION

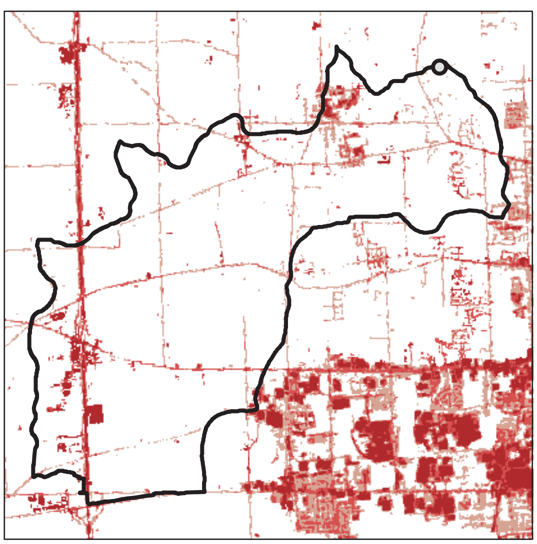
2001 Impervious surface, in percent

High : 100

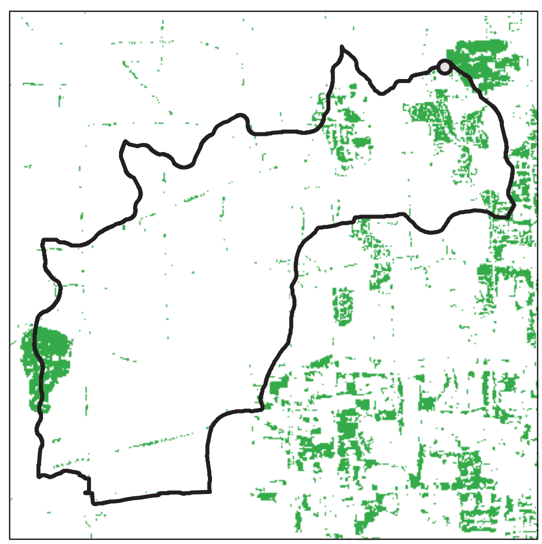
Low : 0

- Study watershed boundary
- Sampling site

C. Developed land (low, medium and high intensity = 10.38 percent)



D. Developed land (open space = 5.99 percent)



EXPLANATION

2001 Land cover

- Developed, low density
- Developed, medium density
- Developed, high density
- Study watershed boundary
- Sampling site

0 1 2 MILES

0 1 2 KILOMETERS

EXPLANATION

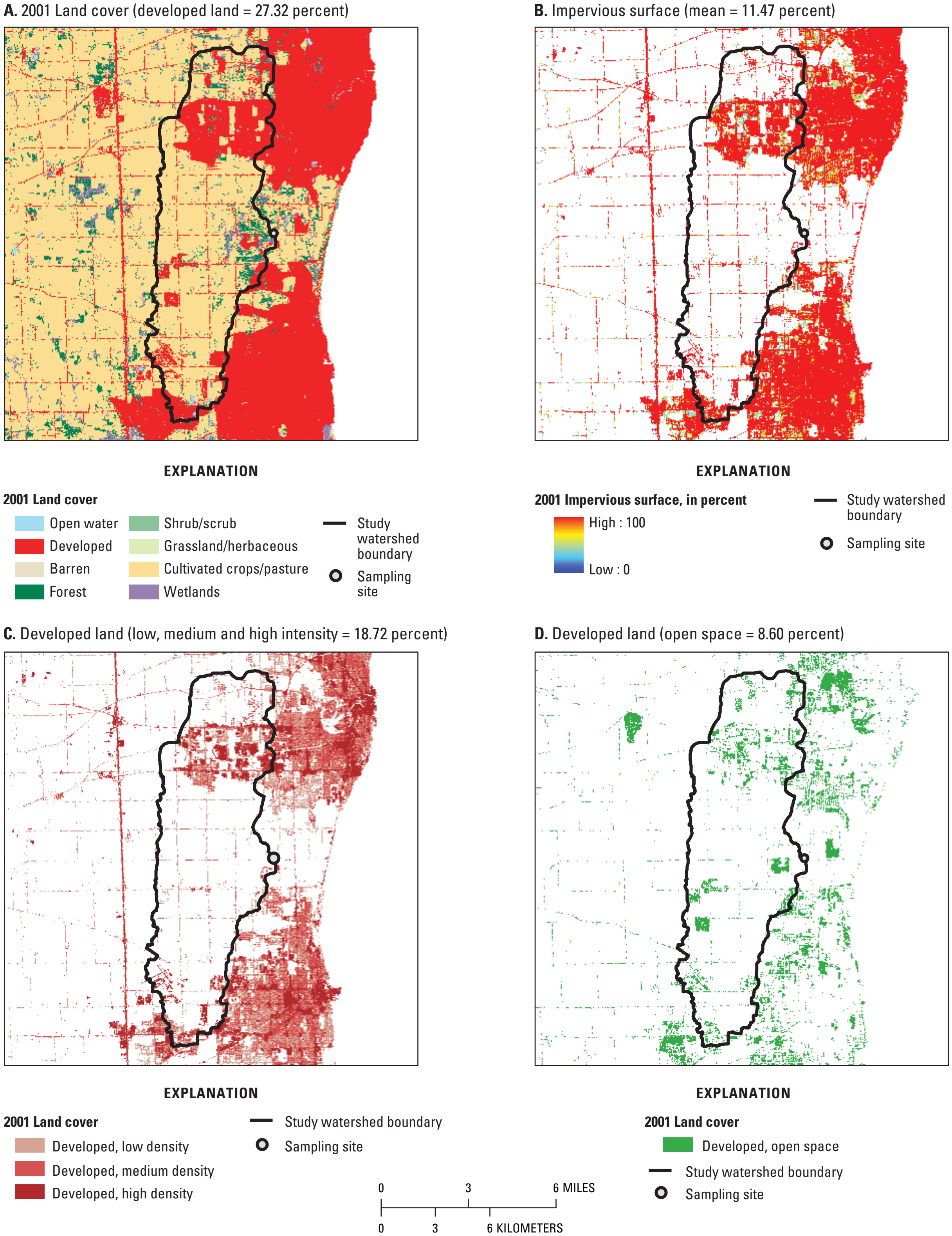
2001 Land cover

- Developed, open space
- Study watershed boundary
- Sampling site

Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

Pike River at County Highway A near Kenosha, Wis.

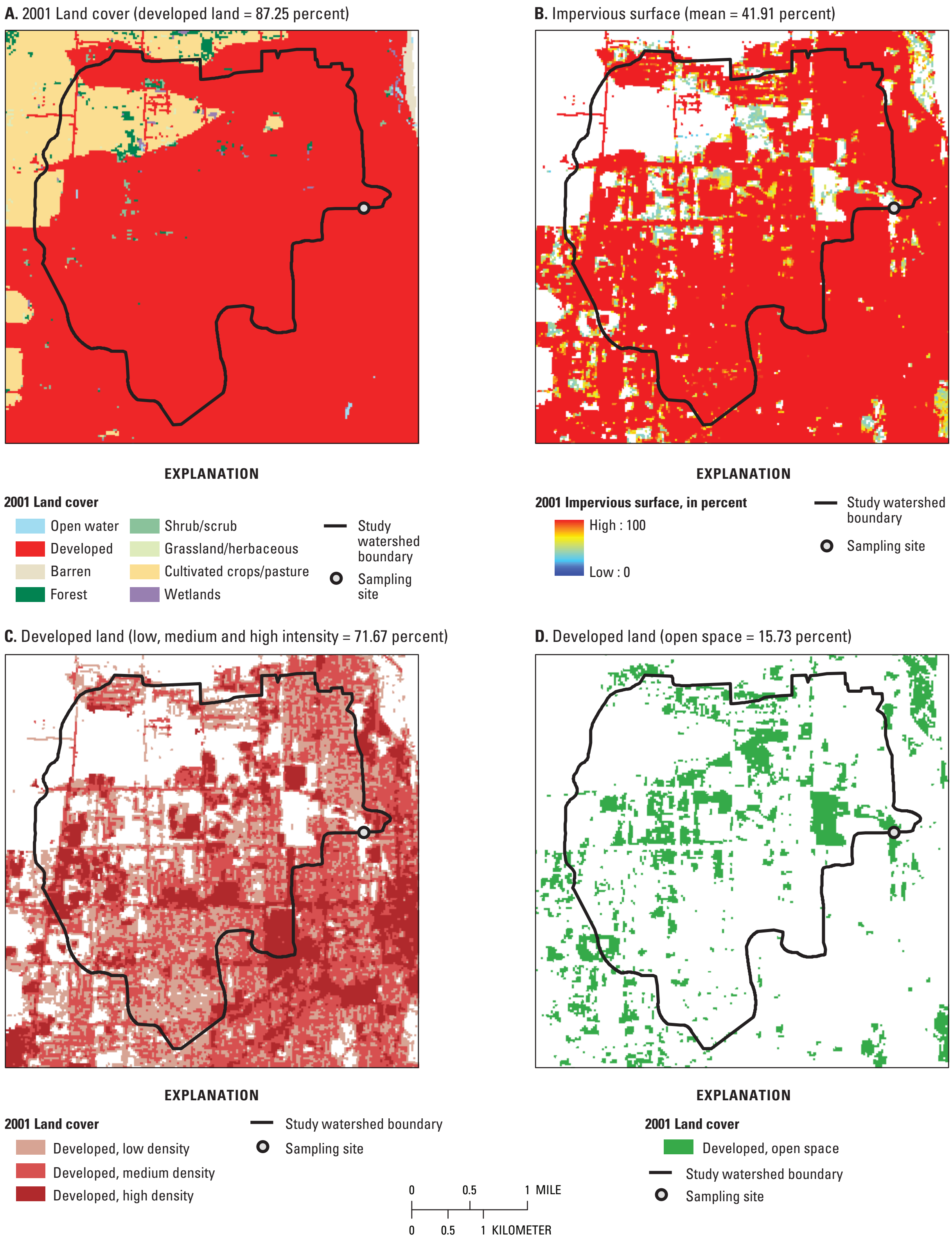
(PIKR; site 27; urban intensity index value = 53.05)



Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

Pike Creek at 43rd St. at Kenosha, Wis.

(PIKC; site 28; urban intensity index value = 83.23)

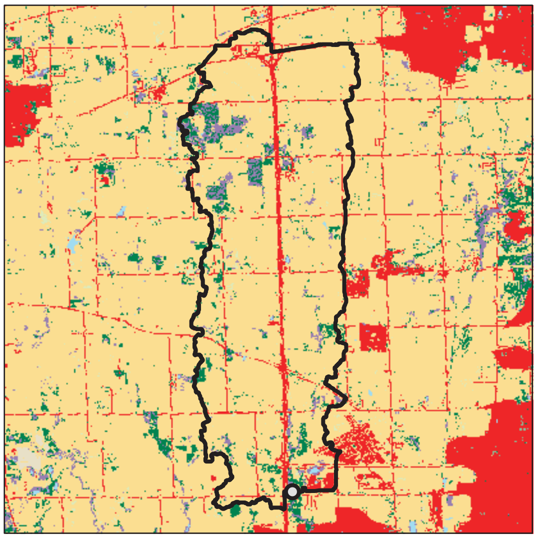


Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

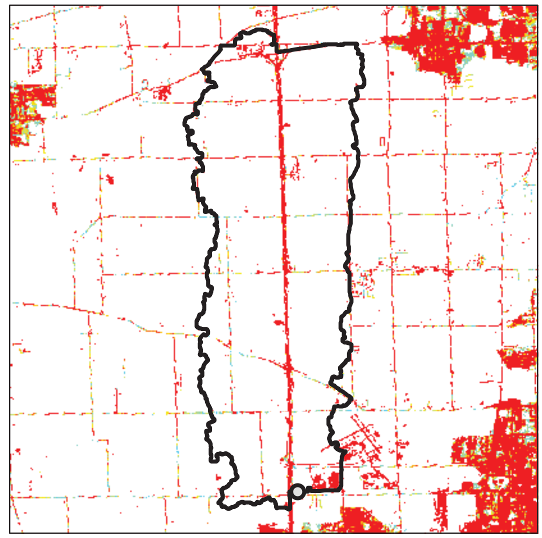
Kilbourn Ditch at 60th St. near Kenosha, Wis.

(KILB; site 29; urban intensity index value = 27.36)

A. 2001 Land cover (developed land = 7.43 percent)



B. Impervious surface (mean = 3.89 percent)



EXPLANATION

2001 Land cover

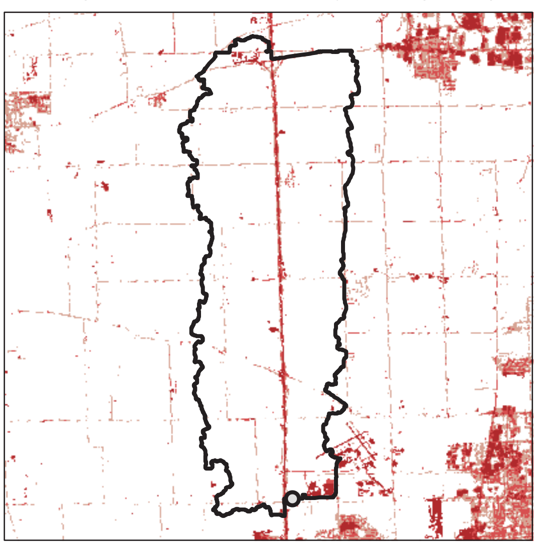
- Open water
- Developed
- Barren
- Forest
- Shrub/scrub
- Grassland/herbaceous
- Cultivated crops/pasture
- Wetlands
- Study watershed boundary
- Sampling site

EXPLANATION

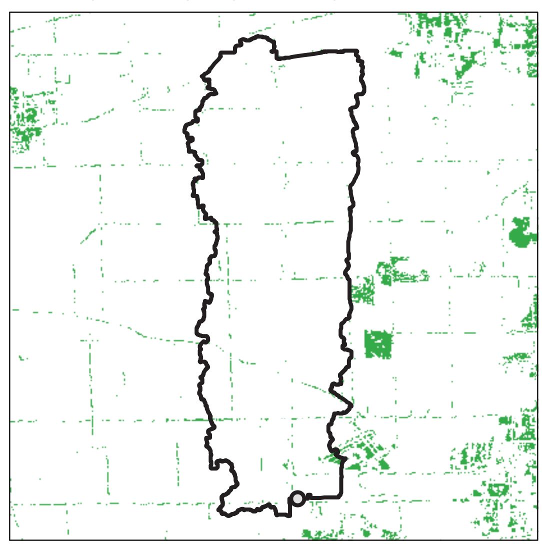
2001 Impervious surface, in percent

- High : 100
- Low : 0
- Study watershed boundary
- Sampling site

C. Developed land (low, medium and high intensity = 6.17 percent)



D. Developed land (open space = 1.21 percent)



EXPLANATION

2001 Land cover

- Developed, low density
- Developed, medium density
- Developed, high density
- Study watershed boundary
- Sampling site

EXPLANATION

2001 Land cover

- Developed, open space
- Study watershed boundary
- Sampling site

0 1.25 2.5 MILES

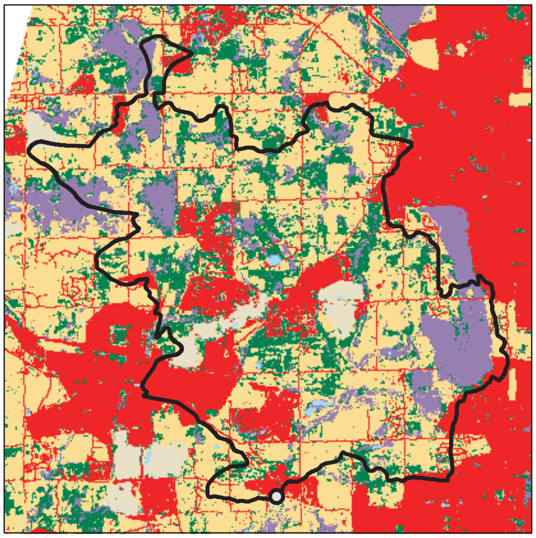
0 1.25 2.5 KILOMETERS

Appendix 7. Maps showing: (**A**) 2001 land cover; (**B**) impervious surface; (**C**) low-, medium- and high-intensity developed land cover; and (**D**) open-space developed land cover for 30 watersheds in the Milwaukee to Green Bay, Wis., study area—Continued. [2001 land-cover and percentage of impervious surface derived from Falcone and Pearson (2006). Values calculated for entire watershed.]

Fox River at River Rd. near Sussex, Wis.

(FOXR; site 30; urban intensity index value = 39.99)

A. 2001 Land cover (developed land = 20.15 percent)

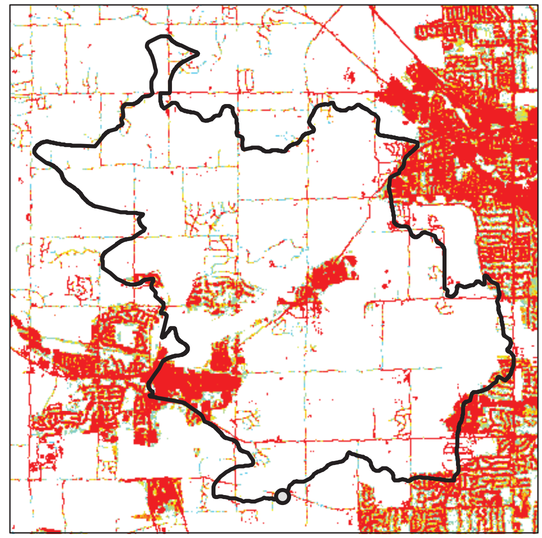


EXPLANATION

2001 Land cover

Open water
Developed
Barren
Forest
Shrub/scrub
Grassland/herbaceous
Cultivated crops/pasture
Wetlands
Study watershed boundary
Sampling site

B. Impervious surface (mean = 5.55 percent)



EXPLANATION

2001 Impervious surface, in percent

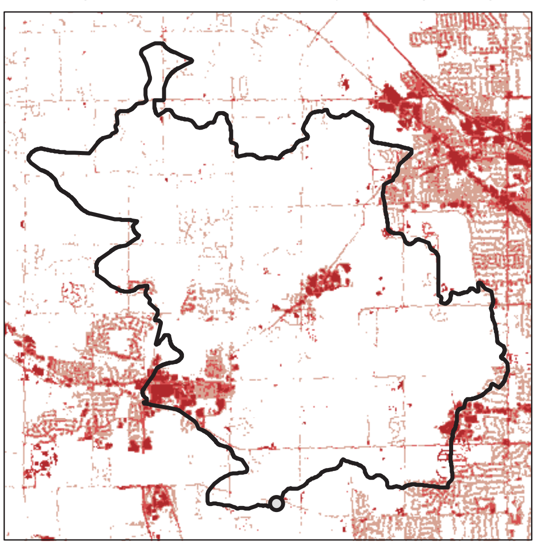
High : 100

Low : 0

Study watershed boundary

Sampling site

C. Developed land (low, medium and high intensity = 9.88 percent)

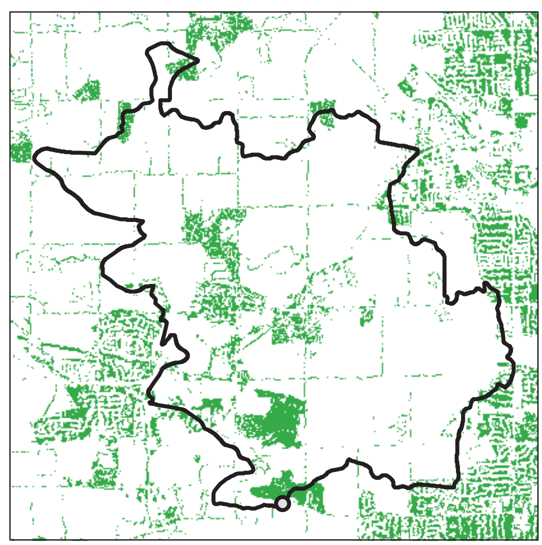


EXPLANATION

2001 Land cover

Developed, low density
Developed, medium density
Developed, high density
Study watershed boundary
Sampling site

D. Developed land (open space = 10.27 percent)



EXPLANATION

2001 Land cover

Developed, open space
Study watershed boundary
Sampling site

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Richards and others—**Effects of Urbanization on Stream Ecosystems, Milwaukee to Green Bay, Wisconsin, 2003–2004**—Scientific Investigations Report 2006–5101–E